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EFFECTS OF FEED ADDITIVES AND BODY WEIGHT ON GROWTH
PERFORMANCE AND CARCASS CHARACTERISTICS OF BEEF FINISHING
CATTLE

by

Curtis J. Bittner

A DISSERTATION

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Under the Supervision of Professors Galen E. Erickson and Matt K. Luebke

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EFFECTS OF FEED ADDITIVES AND BODY WEIGHT ON GROWTH
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Curtis J. Bittner, Ph.D.

University of Nebraska, 2016

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A pooled-analysis of feedlot pens examined the effects of steer age (calf-fed, short yearling, long yearling) and initial body weight on feedlot growth performance. Feed efficiency decreased linearly as initial body weight increased for all age groups of steers.

Three feedlot experiments evaluated the effects of NEXT ENHANCE (EO) and monensin/tylosin (MT) on growth performance and carcass characteristics in beef finishing diets. In Exp. 1, there were no MT x EO interactions for finishing performance and carcass characteristics. Feeding MT resulted in a 3.9% improvement in G:F compared to steers fed no MT. Feed efficiency was not different between steers fed EO and those not fed EO. In Exp. 2, EO dose (0, 75, 150, 225, or 300 mg/steer daily of EO) was evaluated. Increasing EO dose linearly decreased DMI, but ADG was not different among treatments. Feed efficiency linearly increased as EO dose increased. Feeding EO at 225 and 300 mg/steer daily improved G:F 4.4 and 3.8% compared to steers fed 0 EO. In Exp. 3, concentration of EO (0, 16.5, 33.1, or 49.6 mg/kg of EO) was evaluated. Concentration of EO had no effect on DMI, ADG, or G:F.

Two experiments evaluated the effects of ractopamine hydrochloride (RAC) dose and duration on growth performance and carcass characteristics of finishing steers. In Exp. 1, RAC dose (0 or 200 mg/steer daily) and RAC duration (28 or 42 d prior to harvest) were evaluated. Hot carcass weight was 6.0 kg heavier for steers fed 200 mg/steer daily of RAC for 28 d compared with steers fed 0 RAC for 28 d. Feeding 200 mg/steer daily of RAC increased HCW 4.0 kg over steers fed 0 RAC for 42 d. In Exp. 2, RAC dose (0, 300, and 400 mg/steer daily) and RAC duration (14, 28, or 42 d) were evaluated. Feeding 300 mg/steer daily of RAC for 28 and 42 d increased HCW by 5.1 and 7.6 kg compared to steers fed 0 RAC. Additionally, feeding 400 mg/steer daily of RAC for 28 or 42 d increased HCW by 8.9 and 9.4 kg compared to steers fed 0 RAC.

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CHAPTER I. LITERATURE REVIEW

Introduction

The ability for producers to utilize various backgrounding systems allows the flexibility to target certain marketing dates. Furthermore, backgrounding systems allows producers to provide a constant supply of beef throughout the entire year. In Nebraska, numerous forage sources, such as crop residue and rangeland, are available which provides a tremendous opportunity to utilize various backgrounding systems. At weaning time, heavier, larger framed calves can be placed in the feedlot and be finished as calf-feds, known as an intensive system. Lighter, smaller framed calves can then be grown in a backgrounding system, consisting mainly of forages, which is known as an extensive system. Numerous studies exist evaluating the effects of different backgrounding systems on subsequent feedlot performance (Griffin et al., 2007; Winterholler et al 2008; Adams et al., 2010); however, few data are available evaluating how steer BW and age effect feedlot performance.

Generally, cattle that are placed into an extensive system enter the feedlot at heavier weights and finish at greater BW than calf-feds (Griffin et al. 2007). During the finishing period, ADG and DMI are greater for cattle that have been previously backgrounded prior to entering the feedlot compared with calves that enter the feedlot after weaning (Griffin et al., 2007; Winterholler et al., 2008). Furthermore, G:F is poorer for these heavier weight cattle during the finishing period (Adams et al., 2010). Today, approximately 97.3% of the cattle in the feedlot industry are fed an ionophore, with most producers feeding monensin in finishing diets (Samuelson et al., 2016). Previous

research has shown that monensin decreases DMI (Goodrich et al., 1984; Duffield et al., 2012) and improves feed efficiency (Potter et al., 1985) when provided in feedlot diets. However, the public perception of using antibiotics in livestock production has changed, possibly due to the appearance of antibiotic resistant bacteria that may pose a risk to human health (Benchaar et al., 2008). With this, alternative methods to improve feed efficiency in the feedlot need to be explored.

The feedlot industry in the United States is extremely competitive and profit margins are minimal. With the volatility of markets today, and the addition of environmental factors, makes it challenging for producers to determine optimal marketing dates. As days on feed (DOF) increases in the finishing period, feedlot performance late in the feeding period typically declines (Van Koeveering et al., 1995; Winterholler et al., 2007). Ractopamine hydrochloride (RAC; Elanco Animal Health; Greenfield, IN) is a beta-adrenergic agonist (β -AA) that was approved by the FDA for feeding to beef cattle in 2003. Feeding RAC at the end of the finishing period has been shown to partially offset this reduction in growth performance. However, limited data exist evaluating the effects of feeding RAC over time in the finishing period.

Therefore, the objectives of these experiments were to: 1) to determine how age and BW of steers at feedlot entry effects DMI, ADG, and feed efficiency over the finishing period, 2) evaluate the effects of NEXT ENHANCE essential oils on performance and carcass characteristics of steers fed finishing diets with or without monensin plus tylosin, and 3) evaluate the effects of RAC dose and duration of RAC feeding on growth performance and carcass characteristics of finishing steers.

Beef Production Systems

Traditionally spring born calves are weaned in the fall and are either introduced to an extensive or intensive beef production system. Griffin et al. (2007) defined an intensive production system, which is the predominant of the two systems, where calves are weaned and placed directly into a feedlot and fed a high concentrate diet until harvested, also known as calf-feds. Alternatively, an extensive beef production system is when calves are weaned and backgrounded on a crop residue or harvested forages throughout the winter months. After wintering, these calves can then be placed in the feedlot and fed a high concentrate diet, known as short yearlings, or be further backgrounded on summer grass and enter the feedlot in the fall as long yearlings.

Utilizing both an extensive and intensive system provides producers the flexibility to manage cattle based on the BW and frame of the animal. Typically at weaning time, yearling cattle are smaller framed and lighter BW than calf-feds. The time that cattle spend in the backgrounding phase as yearlings allows for the growth and maturity of the skeletal frame and muscle. On the other hand, calf-feds BW are generally heavier at weaning time and have a larger frame size. Vieselmeyer (1993) stated that if a larger framed, heavier animal is placed into an extensive beef production system than the animal can become overweight which could result in packer discounts due to overweight carcasses, which is further supported by the work of Adams et al. (2010). Therefore, the ability of one to appropriately place cattle into an intensive or extensive beef production system is critical and one must understand the biological differences that exist in cattle.

Effects of Production System on Animal Performance and Carcass Traits

With the use of cloned steers, Harris et al. (1997) conducted two trials to evaluate the effects of calf and yearling feeding systems on feedlot performance and carcass traits. Calf-feds were defined as steers that started the finishing diet immediately after weaning, while the yearling fed steers were allowed to graze bermudagrass pasture for 123 d prior to starting the finishing diet. The first trial evaluated the effects of finishing steers as calf-feds or yearlings and harvesting them at a constant age of 16 months. Calf-feds and yearling steers were on the finishing diet for 217 and 97 d, respectively. The second trial harvested calf-feds and yearling steers at a constant BW of 530 kg. When harvested at a constant age (16 months), feedlot ADG in the feedlot was not different between calf-feds and yearlings. However, due to the greater number of days in the feedlot, calf-feds had heavier BW at harvest, greater dressing percentages, marbling score, and quality grade compared to yearlings. In the second trial, DOF in the feedlot were 224 and 182 d for calf-feds and yearlings, respectively. When steers were fed to a constant end weight, ADG was greater for yearlings than calf-feds in the feedlot. Dressing percent was greater for calf-feds than yearlings; however, there were no differences in marbling score and quality grade between the two treatments. These studies suggest the importance of assessing different cattle types for correct placement of cattle in different management systems.

A nine-year study was conducted by Camfield et al. (1999) to evaluate the effects of different steer growth types, when fed on pasture or in a feedlot, on growth performance and carcass traits. The four different growth types were 1) large-framed-late maturing, 2) intermediate framed-intermediate maturing, 3) intermediate framed-early

maturing, 4) and small framed-early maturing. The breed of steers utilized in this study differed among treatments in order to produce differences in maturing rate and size of the animal. Steers were fed to a common days on feed, regardless of whether steers were pasture or feedlot developed, large-framed-late maturing steers had heavier BW and HCW, larger LM area, and lower marbling scores compared to the other growth types. Alternatively, early maturing steers had greater fat thickness, marbling scores, quality grade, and yield grade compared with late maturing steers, respectively. Camfield et al. (1999) stated that the design of the experiment was not to illustrate differences between development regimens, pasture or feedlot, but to characterize differences in carcass characteristics based on different growth types of cattle. These authors concluded that matching the growth type of cattle to the development regimen is critical for optimal steer growth and development, as well as adequate nutrients must be available.

Adams et al. (2010) evaluated two years of data (288 steers/yr) comparing feedlot performance of steers that entered the feedlot at different times. Each year, steers were sorted from one pool of cattle. Treatments consisted of 1) calf-fed (entering the feedlot at receiving), 2) summer yearling (grazed during winter and entering the feedlot in May) and 3) fall yearling (grazed during winter and summer and entering the feeding in September). Initial BW at feedlot entry was greatest for fall yearling, intermediate for summer yearling, and least for calf-fed, which was expected by the design of the experiment. Dry matter intake and ADG were greatest for fall yearlings compared to all other treatments. Thus, feed efficiency was poorest for fall yearlings and greatest for calf-fed. The daily DMI as percent of BW was 2.22, 2.33, and 2.43% for calf-fed, short yearling, and long yearling, respectively. When comparing carcass characteristics, HCW

and LM area were greatest for fall yearlings compared to short yearling and calf-fed steers. Fat thickness was not different between calf-feds (1.32 cm) and short yearlings (1.35 cm) but were greater than long yearlings (1.26 cm). This would suggest that the calf-fed and short yearling steers were finished at a similar fat thickness. Long yearling steers would have required a greater number of DOF to reach the same fat thickness. However, feeding the long yearlings longer, could have resulted in an increase in the number of overweight carcasses.

Griffin et al. (2007) evaluated eight years of data that compared calf-fed versus long-yearling systems and the effects on feedlot performance. The calf-fed system included 804 steers in 80 pens and the long yearling system represented 302 steers in 18 pens. Griffin et al. (2007) reported that initial BW at receiving was lighter for long yearling steers compared to calf-fed, which was result of experimental design. Feedlot initial BW and final BW were greater for long yearlings compared with calf-feds. Average daily gain was 0.33 kg greater for long yearlings compared to calf-feds. Long yearlings consumed more DM/d compared with calf-feds; however, G:F was 18.7% greater for calf-feds compared with long yearlings, respectively. Total DOF in the feedlot was 168 and 90 d for calf-fed and long yearlings. Hot carcass weight was 24 kg greater for long-yearlings compared with calf-feds. Calf-feds fat thickness was 0.15 cm greater than long yearlings; however, marbling score was not different between the two systems. There were no differences in the percent of carcasses grading USDA Choice or greater or USDA Yield Grade. Griffin et al. (2007) concluded that when long yearlings are fed in the feedlot, ADG is increased and the total amount of feed that they consume during this period is less than calf-feds. However, this decrease in total amount of feed

consumed is strictly due to the fewer days that long yearlings spend in the feedlot compared to calf-feds. Therefore, long yearlings require more total days of ownership to reach harvest than calf-feds.

Winterholler et al. (2008) conducted a two year study evaluating the effects of calf-fed versus yearling systems on feedlot performance and carcass characteristics. Steers were either placed on a high concentrate finishing diet (calf-feds) or grazed wheat pasture for 164 d before feedlot entry (yearlings). Feedlot initial BW and DOF was 228 kg and 169 d for calf-feds and 445 kg and 88 d for yearlings. Final BW was 87 kg heavier for yearlings compared to calf-feds. Yearling ADG and DMI were greater and G:F was poorer compared to calf-fed steers. Feed efficiency was 21.1% poorer for yearlings compared to calf-feds. Although DMI was greater for yearlings compared to calf-feds, when DMI was expressed as percentage of mean feeding weight, DMI was not different between the two systems. Calf-fed DMI was 2.42% of BW whereas DMI for yearlings were 2.35% of BW. For carcass characteristics, HCW was 55 kg heavier for yearlings compared with calf-feds, and LM area was greater for yearlings. Fat thickness, marbling score, USDA Yield Grade, and the percent of carcasses grading Choice were not different between the two systems.

The effect of age at feedlot entry on growth performance and carcass characteristics were evaluated by Schoonmaker et al. (2002). Steers were placed in the feedlot at 111 (early weaned), 202, or 371 (yearling) d of age and all steers were harvested at a fat thickness of 1.27 cm. Yearling steers gained faster than steers that were placed in the feedlot at 202 or 111 d of age (1.88, 1.68, and 1.62 kg/d, respectively).

Early weaned steers spent the most days in the feedlot, while yearling steers spent the fewest. Dry matter intake was lowest for early weaned, intermediate for calves that were placed in the feedlot at 202 d of age, and greatest for yearlings. While in the feedlot, feed efficiency was poorest for yearling steers, followed by calves that entered the feedlot at 202 d of age, and greatest for calves that entered the feedlot at 111 d of age. Final BW was 65 and 165 kg heavier for steers that entered the feedlot at 202 and 371 d of age compared to steers that entered the feedlot at 111 d of age. Furthermore, HCW was 43.3 and 99.0 kg heavier for steers entering the feedlot at 202 and 371 d of age compared with early weaned, respectively. Delaying the time at which steers entered the feedlot had no effect on dressing percent, increased LM area, and decreased marbling score. Steers that were placed in the feedlot at 111 or 202 d of age had decrease yield grades, fewer carcasses grading Select, and higher quality grades than yearling steers.

Sainz and Vernazza Paganini (2004) evaluated the effects of different grazing and feeding periods on feedlot performance. Steers were allocated to one of 3 groups (calf-fed, short yearling, and long yearling) and placed on a finishing diet at 180, 300, and 550 d of age and 230, 300, and 425 kg BW, respectively. Using ultrasound, all groups of steers were on feed until a common fat thickness of 1.15 cm was reached. In the feedlot, DOF were 188, 158, and 94 for calf-fed, short yearlings, and long yearlings, respectively. Feedlot ADG was not different among groups of steers but showed a tendency for steers that were placed in the feedlot at a heavier BW to have greater ADG. Dry matter intake during the finishing period was lowest for calves (8.58 kg/d), intermediate for summer yearlings (10.33 kg/d), and greatest for steers that were backgrounded as long yearlings (12.42 kg/d). Feed efficiency was 0.142, 0.140, and 0.124 for calf-fed, short yearlings,

and long yearlings, respectively. Feed efficiency was 11.3% greater for steers fed as calf-feds compared to long yearlings. Final BW was greatest for long yearlings, followed by short yearlings, and least for calf-feds. This would suggest that by delaying the time of which steers enter the feedlot (backgrounding them on forage) increases the mature size of the animal. Hot carcass weight were 294, 315, and 331 kg for calf-fed, short yearlings, and long yearlings, respectively. No differences in fat thickness between groups of steers were observed, which was expected. Furthermore, LM area, marbling scores, yield grade, and quality grade were not different among groups of steers. Results from this study suggest that prolonging the backgrounding period decreased the number of days needed in the feedlot. Furthermore, increasing the backgrounding period resulted in older cattle being marketed at heavier weights, at the same fat endpoint.

Guretzky et al. (2006) placed steer calves on feed using three different systems consisting of calf-feds, short yearlings, or long yearlings. The average BW at feedlot initiation was 250, 286, and 380 kg and average age was 6.1, 11.8, and 16.4 months for calf-feds, short yearlings, and long yearlings, respectively. Dry matter intake during the feedlot phase was greatest for long yearlings (13.1 kg/d), intermediate for short yearlings (10.7 kg/d), and least for calf-feds (8.4 kg/d). Average daily gain was greatest for short (1.7 kg/d) and long yearlings (1.8 kg/d) and least for calf-feds (1.3 kg/d). Feed efficiency was poorest for long yearlings; however, G:F was not different between calf-feds and short yearlings. As expected, HCW was lightest for calf-feds, intermediate for short yearlings, and heaviest for long yearlings. Marbling score, fat thickness, yield grade, and the percentage of steers grading choice were not different among systems.

A meta-analysis, consisting of 10 experiments conducted by Lancaster et al. (2014), evaluated the effects of calf-fed versus long yearling systems on finishing performance and carcass characteristics. As expected, initial BW was greater for steers starting the finishing diet as a long yearling (376.5 kg) compared to a calf-fed (251.3 kg). Long yearling cattle had greater ADG and DMI but poorer G:F compared with calf-feds. Feed efficiency was 13.4% greater for calf-feds than long yearlings, which would agree with much of the previous data when comparing the two systems. Final BW was 26.7 kg greater for long yearlings compared with calf-feds. For carcass characteristics, HCW and LM area tended to be greater for long yearlings compared with calf-feds. Fat thickness was greater for calf-feds (1.38 cm) compared to long yearlings (1.20 cm). The authors concluded that if the long yearlings were fed to a similar fat thickness, one would expect HCW to be greater for long yearlings compared to calf-feds. No differences in marbling score and yield grade were observed between the two treatments.

Hicks et al. (1990) analyzed feed records from a commercial feedlot to determine the relationship of DMI by steers to initial BW at which cattle were received into the feedlot. This dataset included a 3-year period, from 1983 to 1985, consisting of 296,367 steers. Dry matter intake patterns were dramatically different between calf-feds and yearlings throughout the feeding period. For calf-feds, DMI increased the first 70 d and then plateaued off for the remaining 100 d. However for yearlings, DMI increased linearly the first 40 to 50 d, plateaued for about 40 d, and then decreased the remained 40 d of the feeding period. Furthermore, these authors determined how current BW effects DMI. Steers were categorized based upon mean initial BW of 227 (216 to 239), 273 (262

to 284), 318 (307 to 329), and 364 (352 to 375) kg. These authors concluded that as initial BW increased, DMI increased.

Hicks et al. (2015) compiled weekly DMI data from 2,329 pens (minimum of 50 steers per pen) fed high concentrate diets for an average of 158 d in one southern Great Plains feedlot. Dry matter intake was different based on initial weight entering the feedlot so pens were grouped based on initial weight (216 to 443 kg) into 10 sets. Pens of steers with greater initial weight had greater DMI and ADG but poorer feed conversions (F:G) compared to steers with lighter initial weight entering the feedlot. Dry matter intake, when expressed as percentage of mean weight of steers within each pen, was lower for pens of steers with heavier initial weights and decreased linearly over the feeding period.

Zinn et al. (2008) compiled data from 15 different feedlot in western United States and Canada and evaluated the effects of initial BW on feedlot performance. These authors conclude that as DMI and ADG were greater for steers with a heavier initial BW compared to those of lighter weights. As initial BW increased for steers, ADG increased linearly. However, steers with a heavier initial BW resulted in poorer G:F.

Lastly, Reinhardt et al. (2009) evaluated the effects of feedlot arrival BW of steers on growth performance and carcass characteristics. The dataset consisted of 15,631 steers that were fed in feedlots located in southwest Iowa over a 4-year time period. The dataset was categorized based upon initial BW entering the feedlot (≤ 226 , 227 to 272, 272 to 317, 318 to 362, and ≥ 363 kg). Increasing initial BW entering the feedlot linearly decreased ADG with steers having an initial BW of ≤ 226 kg gaining 1.60 kg/d compared

to steers with an initial BW of ≥ 363 kg gaining 1.46 kg/d. Final BW and HCW increased as initial BW group increased. Carcasses from steers with an initial BW ≤ 226 kg were 59.4 kg lighter than steers with an initial BW ≥ 363 kg. Increasing initial BW into the feedlot increased fat thickness and LM area but decreased marbling score.

Results from these studies illustrate the effects that different backgrounding systems have on subsequent feedlot performance. Delaying the time prior to feedlot entry, such as backgrounding cattle on forages, results in poorer feed efficiency in feedlot. However, these cattle require fewer days in the feedlot and are marketed at heavier weights. These studies demonstrate the importance of understanding different cattle types and appropriately placing them into different systems.

Essential Oils

The use of feed additives, such as ionophores, are commonly provided in ruminant diets to improve the efficiency of energy and protein utilization in the rumen (Van Nevel and Demeyer, 1998). Today, the most commonly used ionophore in the feedlot industry is monensin, followed by lasolacid (Samuelson et al., 2016). Since its approval in 1975, previous research has shown that monensin decreases DMI (Goodrich et al., 1984; Duffield et al., 2012) and improves feed efficiency (Potter et al., 1985) when provided in feedlot diets. However, the public perception of using antibiotics in livestock production has changed, possibly due to the appearance of antibiotic resistant bacteria that may pose a risk to human health (Benchaar et al., 2008). Furthermore, in January of 2006 the European Union banned the use of antibiotics, such as monensin, as growth

promoters in animal feed. With this, alternative methods to modulate ruminal fermentation to enhance animal productivity and improve feed efficiency are needed.

General Information on Essential Oils and Different Types

Certain plants produce secondary metabolites (Greathead, 2003) which are used as a natural protection against microbial and insect attack (Wallace, 2004). Secondary metabolites are classified into three categories: saponins, tannins, and essential oils (EO). For the purpose of this literature review, EO will be the main area of focus. Essential oils are secondary plant metabolites that are obtained from the plant volatile fraction by steam distillation or with the use of organic-solvents (Wallace, 2004; Calsamiglia et al., 2007). Various parts of the plants can be utilized to obtain EO such as the leaves, flowers, roots, stems, bark, and seeds (Chaves et al., 2008a). However, Dorman and Deans (2000) described that different parts of the same plant can vary in composition of EO that is extracted. In addition, the concentrations of EO can vary depending on the stage of plant growth, amount of moisture received, light, and temperature (Hart et al., 2008).

According to Calsamiglia et al. (2007) the term “essential” derives from “essence,” which means smell or taste and relates to the properties of these substances in providing specific flavors and odors to many plants. Most EO occur in two chemical groups: terpenoids and phenylpropanoids. Terpenoids are the most abundant, with approximately 15,000 different compounds have been described in the literature (Gershenzon and Croteau, 1991). Terpenoids are derived from a five-carbon unit (C_5H_8), sometimes called an isoprene unit, and are classified depending on the number of five-carbon units in their structure (Gershenzon and Croteau, 1991). Terpenoids are

composed of a basic isoprene unit that is arranged in a cyclic ring structure and can occur as hemiterpenoids, monoterpenoids, sesquiterpenoids, diterpenoids, triterpenoids, and tetraterpenoids (C_5 , C_{10} , C_{15} , C_{20} , C_{30} , and C_{40} , respectively), with the most important components of EO belonging to the monoterpenoid and sesquiterpenoid families (Gershenzon and Croteau, 1991). Examples of terpenoids would include carvacrol and thymol, which are both found in oregano and thyme (Calsamiglia et al., 2007). Phenylpropanoids, which are not the most common compounds of EO, are the second chemical group of which EO occur and they are described as an aromatic ring of six carbons that has a side chain of three carbons attached to it (Calsamiglia et al., 2007). Common phenylpropanoids include cinnamadehyde (cinnamon), eugenol (clove bud and cinnamon), and anethol (anise; Calsamiglia et al., 2007).

Multiple theories have been suggested to explain the mode of action for EO on antibacterial activity. The most accepted theory is that essential oils interact with bacteria cell membranes (Calsamiglia et al., 2007). Essential oils have high affinity for lipids in bacterial cell membranes due to their hydrophobic nature, which allows EO to interact with cell membranes and accumulate in the lipid bilayer of bacteria (Calsamiglia et al., 2007). This interaction affects the membrane structure which causes the de-stability of the membrane, which in turn causes intracellular leakage and causes a decrease in the transmembrane ionic gradient (Calsamiglia et al., 2007). In order to counteract this, bacteria use ion pumps to facilitate transport across the membrane. However, during this process a great deal of energy is exerted and bacterial growth begins to diminish, thereby altering rumen fermentation (Griffin et al. 1999, Calsamiglia et al., 2007). Given this theory, Burt (2004) suggested that gram-positive bacteria would be more susceptible to

EO than gram-negative bacteria. This is because gram-negative bacteria have an outer layer surrounding their cell wall that acts like a barrier and limits access for hydrophobic compounds. In contrast, Helander et al. (1998) demonstrated that EO disrupted the outer cell membrane of gram-negative bacteria which inhibited their growth.

Rumen Fermentation

Ionophores, commonly monensin, alter rumen microbial fermentation to improve the energy status of the animal by increasing the production of propionic acid and decreasing the proportion of acetate and butyrate. Similarly, secondary plant metabolites have been shown to have antimicrobial activity (Cowan, 1999) against some gram-positive and gram-negative bacteria. However, studies evaluating the effects of essential oils on rumen microbial fermentation differ and are pH and diet dependent which would suggest that their use may only be beneficial under specific growth conditions (Calsamiglia et al., 2007).

Busquet et al. (2005) evaluated the effects of cinnamaldehyde and garlic oil on rumen fermentation using continuous culture fermenters. Additionally, a no additive (control, negative control) and monensin (positive control) treatment were included in the study. The fermenters were inoculated with rumen fluid from heifers that were fed a 50:50 alfalfa hay:concentrate diet. Compared to the control, total VFA concentrations were not different between cinnamaldehyde and garlic oil. As expected, monensin provided fermenters caused an increase in the proportion of propionate and a decrease in the proportions of acetate and butyrate compared with the control, cinnamaldehyde, and garlic oil treatments, respectively. Addition of cinnamaldehyde (31.2 mg/L) to

continuous cultures decreased the molar proportion of acetate, increased the molar proportion of propionate, but had no effect on molar proportion of butyrate compared with the control. Providing fermenters with garlic oil (31.2 mg/L) had no effect on the molar proportions of acetate, propionate, or butyrate compared with the control. Alternatively, providing a greater concentration of garlic oil (312 mg/L) to fermenters resulted in a decrease in the molar proportion of acetate and an increase in the molar proportions of propionate and butyrate compared with control. Busquet et al. (2005) concluded that providing continuous culture fermenters with cinnamaldehyde (31.2 mg/L) and garlic oil (312 mg/L) resulted in similar changes in molar proportions of VFA as monensin, with the exception of butyrate. The use of cinnamaldehyde and garlic oil caused changes in the rumen fermentation profile; however, the mode of action for these EO may be different from that of monensin.

In high roughage diets, consisting mainly of alfalfa hay and corn silage, the effects of supplementing a basal diet (control) with raw garlic bulb and garlic oil on ruminal fermentation characteristics as an alternative to monensin in sheep were evaluated by Anassori et al. (2011). Rumen fluid pH was not different between treatments and averaged 6.7. Total VFA concentrations were not different between treatments. However, acetate concentrations decreased whereas propionate concentrations increased when feeding raw garlic bulb and garlic oil compared with control. Feeding raw garlic bulb and garlic oil resulted in a shift in acetate and propionate production; however, the greatest improvements in concentrations of these VFAs were observed when feeding monensin. Results from this study suggest that ruminal fermentation can be altered with the use of raw garlic bulb and garlic oil, but to a

lesser extent when compared with monensin. Furthermore, Khorrami et al. (2015) supplemented steers with a basal diet (control) with thyme oil (500 mg/kg DM), cinnamon oil (500 mg/kg DM), or monensin (33 mg/kg DM) and evaluated the effects on rumen fermentation. The basal diet consisted mainly of alfalfa hay, corn silage, and wheat bran. Ruminal pH was not affected by treatments and averaged 6.24. Total VFA concentrations were not different between control, thyme oil, and cinnamon oil treatments. The molar proportion of acetate decreased whereas the molar proportion of propionate increased for steers supplemented with monensin and thyme oil compared with the control. The addition of thyme oil and cinnamon oil had no effect on the molar proportion of butyrate compared with the control. Supplementing with thyme oil, cinnamon oil, and monensin decreased the acetate to propionate ratio compared to control. These authors concluded that cinnamon oil and thyme oil could be potential alternatives to monensin when used as rumen fermentation modifiers.

Meyer et al. (2009) evaluated the effects of different feed additives in finishing diets on rumen fermentation characteristics of steers. Treatments consisted of no feed additives (control), essential oil mixture, experimental essential oil mixture, and monensin. Feed additives were supplied daily at concentrations of 90.0, 90.0, and 28.2 mg/kg (DM basis) for treatments essential oil mixture, experimental essential oil mixture, and monensin, respectively. A basal diet was provided to all treatments which consisted of 66.0% HMC, 16.5% DRC, 7.5% alfalfa hay, 5% molasses, and 5% supplement (DM basis). Rumen pH averaged 5.64 across all treatments and did not differ. Among treatments, no differences in DMI, OM intake, and apparent total tract DM or OM digestibility were observed. Total VFA and acetate concentrations tended to be greater

for treatments with EO compared to the control treatment. No differences in concentrations of propionate or butyrate and the ratio of acetate to propionate were observed among treatments. Furthermore, evaluation of VFA data on a molar proportion basis, no differences in the proportion of acetate, propionate, and butyrate were observed for any treatments. These authors concluded that the use of EO on ruminal fermentation have little impact.

Similarly, a metabolism study was conducted by Westerhold et al. (2013) evaluating the effects of feeding increasing concentrations of NEXT ENHANCE (Novus International, Inc., St. Charles, MO) EO on nutrient digestibility and fermentation in finishing diets. The ingredients of NEXT ENHANCE are a proprietary blend of calcium carbonate, rice hulls, cinnamaldehyde, silica, mono and diglycerides of fatty acids, garlic oil, and mineral oil. Treatments consisted of NEXT ENHANCE concentrations of: 0, 7.5, 15, 27.5, and 30 mg/kg diet DM. One basal diet was provided to all treatments and consisted of 70.5% ground corn, 15.1% dried distillers grains, 8.0 alfalfa hay, and 6.4% supplement (DM basis). Concentration of NEXT ENHANCE had no effect on rumen pH. Dry matter intake decreased quadratically as concentration of NEXT ENHANCE increased, with intake being lowest when steers were fed 7.5 and 15 mg/kg diet DM of NEXT ENHANCE and greatest when feeding 30 mg/kg diet DM of NEXT ENHANCE. Total tract NDF digestibility tended to decrease linearly, but OM and N digestibility were not affected by concentration of NEXT ENHANCE. Total VFA and acetate concentrations decreased quadratically as NEXT ENHANCE concentration in the diet increased. These authors observed a quadratic decrease in the molar proportions of acetate as concentration of NEXT ENHANCE increased. Furthermore, total VFA

concentrations decreased quadratically as concentration of NEXT ENHANCE increased. No differences in molar proportions of propionate, butyrate, or acetate to propionate ratio were observed with increasing concentrations of NEXT ENHANCE.

Furthermore, Yang et al. (2010b) conducted a study evaluating the effects of eugenol supplementation on rumen fermentation characteristics in high concentrate diets. Treatments consisted of supplementing increasing doses of eugenol. Rates of eugenol (extracted from cloves) supplemented were 0, 400, 800, and 1600 mg/heifer daily. The basal diet consisted of 80% dry-rolled barley grain, 15% barley silage, and 5% supplement (DM basis). Mean daily ruminal pH did not differ among treatments and ranged from 6.12 to 6.23. Increasing eugenol supplementation rate had no effect on total VFA concentrations. Molar concentrations of acetate linearly decreased as eugenol supplementation rate increased; however, eugenol supplementation rate had no effect on molar concentrations of propionate and butyrate. Molar proportion of propionate tended to linearly increase whereas the acetate to propionate ratio tended to decrease as eugenol supplementation rate increased. Eugenol supplementation rate had no effect on the molar proportions of acetate and butyrate. These authors concluded that even though eugenol supplementation rate altered the VFA pattern of fermentation, these small improvements may not be sufficient to improve the growth rate of cattle fed high concentrate diets.

Effects of Essential Oils on Growth Performance and Carcass Characteristics

Benchaa et al. (2005) evaluated the effects of monensin and different levels of a mixture of EO on growth performance of beef cattle. Treatments consisted of control (no additives), monensin (33 mg/kd DM), or a commercially available EO Vertan® (2 and 4

g/steer daily). Vertan is a commercially available EO consisting mainly of thymol, eugenol, vanillin, and limonene. Feed additives were provided once daily in a basal diet that consisted of 75% grass/legume silage, 24% rolled barley, and 1% supplement (DM basis). Dry matter intake was 10 and 8.9% less for steers fed monensin compared with those fed control and EO, respectively. Essential oil dose had no effect on DMI. Average daily gain was similar (1.24 kg/d) between steers fed EO and those fed control and monensin. The addition of EO and monensin had no effect on G:F; however, increasing dose of EO had a quadratic effect on G:F. Feed efficiency was 0.146, 0.154, and 0.131 for steers were fed control, 2 g/steer daily of EO, and 4 g/steer daily of EO, respectively. In a growing diet, consisting mainly of forage, these data would suggest that feeding lower doses of EO results in improved feed efficiency compared with steers fed no additives.

In lambs, Chaves et al. (2008a) examined the effects of not supplementing (control) or supplementing with 200 mg/kg of dietary DM of either cinnamaldehyde, garlic, and juniper berry EO on growth performance and carcass traits in a barley based concentrate diet. Compared to the control, EO had no effect on DMI. Average daily gain was greater for lambs supplemented with cinnamaldehyde and juniper berry compared to lambs fed control and garlic. Although not significant, G:F was numerically greater for lambs fed cinnamaldehyde (0.208) and juniper berry (0.213) compared to control (0.189) and garlic (0.192) fed lambs. Supplementation with cinnamaldehyde, garlic, and juniper berry had no effect on carcass characteristics compared with control. In another study conducted by Chaves et al. (2008b), supplementing lambs with 0.2 g/kg (DM basis) of carvacrol or cinnamaldehyde were evaluated in either barley or corn based diets.

Supplementing with carvacrol or cinnamaldehyde had no effect on DMI, ADG, or feed efficiency in lambs. Conclusions from these studies would suggest that supplementing diets with EO did not improve growth performance in lambs.

Research evaluating the effect of essential oils in feedlot diets is limited and the responses observed on growth performance and carcass traits vary. A feedlot experiment was conducted by Meyer et al. (2009) evaluating the effects of different feed additives on growth performance and carcass characteristics of finishing steers. Four hundred sixty eight yearling steers were used in 50 pens (10 pens/treatment). Treatments consisted of 1) control (no feed additives); 2) essential oil mixture (targeted at 1.0 g/steer daily); 3) experimental essential oil mixture (targeted at 1.0 g/steer daily); 4) essential oil mixture plus tylosin (, targeted at 1.0 g/steer daily and 90 mg/steer daily, respectively; tylosin, Elanco Animal Health, Greenfield, IN); and 5) monensin plus tylosin (targeted at 300 mg/steer daily and 90 mg/steer daily, respectively; monensin, Elanco Animal Health, Greenfield, IN). The essential oil mixture consisted of thymol, eugenol, guaiacol, vanillin, and limonene (Benchaar et al., 2007). The experimental essential oil mixture consisted of linalool, guaiacol, and α -pinene. Dry matter intake was lowest for steers fed monensin plus tylosin; however, no differences in DMI were observed between steers fed control, essential oil mixture, experimental essential oil mixture, and essential oil mixture plus tylosin. Similarly, ADG was not different among treatments. A tendency for a 4.1 and 4.1% improvement in G:F when steers were fed essential oil mixture and experimental essential oil mixture compared with control steers, respectively. These authors suggested that the improvements in G:F when steers were fed essential oil mixture and experimental essential oil mixture were due to the numerical improvement in

ADG that was observed. Essential oils had no effect on HCW, dressing percent, LM area, or marbling score. The percent of total liver abscesses tended to be less for steers fed essential oil mixture (16.6%) compared with control (27.7%). However, the percent of total liver abscesses for steers fed the experimental essential oil mixture (26.6%) were not different from control. Essential oil treatments without tylosin had no effect on the occurrence of severe (A+) liver abscesses compared with steers fed control. Addition of essential oil mixture or experimental essential oil mixture to feedlot diets improved growth performance compared to steers fed no additives.

Yang et al. (2010a) supplemented steers with increasing rates of cinnamaldehyde and evaluated the effects on growth performance and carcass characteristics in finishing diets. Treatments consisted of 0, 400, 800, or 1600 mg/steer daily of CIN. Steers (n = 56) were individually fed a basal diet consisting of 86% dry-rolled barley grain, 9% barley silage, and 5% supplement (DM basis). Dry matter intake tended to increase quadratically with increasing rates of CIN supplementation. Intake was lowest when steers were supplemented with 0 and 1600 mg/steer daily of CIN and greatest when supplementing steers with 400 mg/steer daily of CIN. Supplementation rate had no effect on ADG or G:F. Supplementing steers with CIN had no effect on HCW, dressing percentage, fat thickness, LM area, marbling score, or quality grade.

A finishing study was conducted by Bittner (2012) evaluating the effects of NEXT ENHANCE and monensin/tylosin on feedlot performance and carcass characteristics. The experiment was arranged as a 2×2 factorial with factors being the presence or absence of NEXT ENHANCE and presence or absence of MT. Treatments

consisted of: 1) control, no additives; 2) NEXT ENHANCE; 3) monensin plus tylosin; and 4) NEXT ENHANCE plus monensin and tylosin. NEXT ENHANCE was included at 300 mg/steer daily, monensin at 360 mg/steer daily and tylosin at 90 mg/steer daily. Four hundred calf fed steers were assigned randomly to 40 pens (10 pens/treatment). A common basal diet was used for all four treatments and consisted of 53% DRC, 25% wet distillers grains plus solubles, 16% corn silage, and 6% supplement (DM basis). There were no significant monensin plus tylosin \times NEXT ENHANCE interactions for growth performance or carcass characteristics. Feeding NEXT ENHANCE had no effect on DMI, ADG, or G:F when compared to steers fed no NEXT ENHANCE. Furthermore, no differences in carcass characteristics or the occurrences of liver abscesses were observed when comparing steers fed NEXT ENHANCE to those without NEXT ENHANCE.

Similarly, Westerhold et al. (2013) evaluated the effects of feeding increasing rates of NEXT ENHANCE in finishing diets. Treatments consisted of feeding rates of NEXT ENHANCE 0, 150, 300, and 600 mg/steer daily. Ninety-eight crossbred steers were utilized with 5 replications per treatment. Feeding NEXT ENHANCE had no effect on DMI, ADG, G:F, and final BW when compared with steers fed 0 mg/steer daily of NEXT ENHANCE. For carcass characteristics, no differences were observed for HCW, LM area, and marbling score amongst treatments. Feeding NEXT ENHANCE to steers decreased fat thickness and calculated yield grade compared to steers fed 0 mg/steer daily of NEXT ENHANCE. Results from these studies evaluating the effects of feeding NEXT ENHANCE in finishing diets would suggest that growth performance is not improved during the finishing period.

Beta-adrenergic agonist

The use of growth enhancement technology to improve the growth efficiency of livestock is a common practice used today in the U.S. feedlot industry. According to a recent survey of feedlot consulting nutritionist by Samuelson et al. (2016) reported that approximately 84.8% of the feedlots the nutritionists serviced used some type of beta-adrenergic agonist (β -AA). In the United States there are two β -AA that are approved by the Food and Drug Administration (FDA) for the use in food animal species, ractopamine hydrochloride (RAC; Elanco Animal Health, Greenfield, IN) and zilpaterol hydrochloride (Merck Animal Health; De Soto, KS). In the United States, RAC was approved to be fed to beef cattle in 2003 (FDA, NADA 141-221, 2003) and zilpaterol hydrochloride in 2006 (FDA, NADA 141-258, 2006). Since the recent withdrawal of products containing zilpaterol hydrochloride in the U.S. market, 95.5% of the nutritionist that reported feeding β -AA in feedlots in the U.S. indicated that they are using RAC as their main β -AA (Samuelson et al., 2016). For the purpose of this literature review, the main focus will be on the use of ractopamine hydrochloride in beef cattle.

Mode of action

Beta-adrenergic agonist have been widely used in the livestock industry as a growth promoting tool. Beta-adrenergic agonist are phenethanolamines, which are compounds with a similar structure to naturally occurring catecholamines such as norepinephrine, epinephrine, and dopamine (Scramlin et al., 2010). Beta-adrenergic receptors (β -AR) are present on the surface of almost every type of mammalian cell and are physiologically stimulated by natural catecholamines (Mersmann, 1998). These β -AR are membrane bound receptors that belong to a family of G-protein coupled receptors

that are the binding site for catecholamines (Mersmann, 1998; Mills, 2002b). There are three subtypes of which β -AR are classified and they are β 1-AR, β 2-AR, and β 3-AR, with RAC preferentially binding to β 1-AR (Moody et al., 2000). When administered orally, β -AA binds to a β -AR which can increase protein accretion and decrease fat accretion during animal growth by increasing protein synthesis and decreasing protein degradation (Mersmann, 1998). Since muscle fiber number is fixed at birth, the primary effect of β -AR ligands is to cause muscle fiber hypertrophy (Mills, 2002a). Beta-adrenergic agonist are only approved to be fed during the final days of the finishing period in beef cattle, prior to harvest. As cattle reach maturity, the rate of muscle deposition decreases whereas the rate of fat deposition increases. Therefore, the use of a β -AA, such as RAC, can decrease the rate at which fat is deposited and increase muscle deposition late in the finishing period. Ractopamine hydrochloride is a β 1-AA and is approved for feeding during the last 28 to 42 d of the finishing period at a rate of 10.0 to 30.0 mg of RAC/kg (DM basis) and to provide 70 to 430 mg of RAC/steer daily with no withdrawal period (FDA, NADA 141-221, 2003). Ractopamine hydrochloride is labeled to improve feed efficiency, increase rate of weight gain, and increase carcass leanness in cattle fed in confinement for slaughter (FDA, NADA 141-221, 2003). The use of β -AA to modify body composition and growth rate have long been researched, with RAC being approved as the first β -AA to be used in swine in 2002 (Mills, 2002b).

Impact of β -Adrenergic Agonist on Cattle Performance and Carcass Characteristics

A meta-analysis, consisting of 32 experiments and 26,483 steers, evaluating the effects of RAC dose on growth performance and carcass characteristics was conducted by Pyatt et al. (2013). The average duration for RAC fed was 32 d. Pyatt et al. (2013)

reported a linear increase in live final BW as RAC dose increased. Feeding 100 mg of RAC/steer daily increased live final BW by 3.4 kg whereas feeding 200 mg of RAC/steer daily resulted in an increase of 6.8 kg in live final BW compared to steers not fed RAC. Furthermore, Abney et al. (2007) observed 5.9 and 9.4 kg increases in live final BW when steers were fed 100 or 200 mg of RAC/steer daily for 35 d compared to steers not fed RAC. To a greater extent, Boler et al. (2012) reported a 14.8 kg increase in live final BW when steers were fed 200 mg of RAC/steer daily for 28 d. Conversely, Bryant et al. (2010) conducted a study evaluating the effects of feeding increasing rates of RAC (0, 100, or 200 mg/steer daily) for 28 d and they reported no differences in live final BW among treatments. A large feedlot pen study evaluating the effects of feeding 300 mg of RAC/steer daily for 35 d was conducted by Quinn et al. (2016). These authors reported increases of 9.3 kg in live final BW when steers were fed 300 mg of RAC/steer daily compared with steers not fed RAC. Feeding 300 mg of RAC/steer daily increased live final BW 10.2 kg when compared with steers fed no RAC (Pyatt et al., 2013). Furthermore, Boler et al. (2012) noted a 14.6 kg increase in live final BW when feeding 300 mg of RAC/steer daily for 28 d. Data evaluating the effects of feeding 400 mg of RAC/steer daily are limited; however, Edenburn et al. (2016) and Strydom et al. (2009) reported 7.0 and 14.1 kg increases in live final BW when compared with steers not fed RAC for the last 28 or 30 d.

Carcass-adjusted ADG was 22.0 and 28.4% greater for steers fed 100 and 200 mg of RAC/steer daily compared with steers receiving no RAC (Abney et al., 2007). To a lesser extent, Arp et al. (2014) reported an 8.7% improvement in carcass-adjusted ADG when feeding 200 mg of RAC/steer daily for 28 d. Furthermore, Pyatt et al. (2013)

reported that ADG was 10.4 and 17.2% greater for steers fed 100 and 200 mg of RAC/steer daily compared to steers not fed RAC. However, feeding 300 mg of RAC/steer daily improved carcass-adjusted ADG by 22.2 and 31.6% compared with steers not fed RAC (Avendaño-Reyes et al., 2006; Arp et al., 2014). Similarly, Quin et al. (2016) observed a 23.3% improvement in carcass-adjusted ADG when steers were fed 300 mg of RAC daily compared with those not fed RAC. Carcass-adjusted ADG was 24.6% greater for steers fed 400 mg of RAC/steer daily compared with steers fed no RAC (Arp et al., 2014). The aforementioned studies only reported growth performance during the time RAC was being fed instead of reporting growth performance over the entire feeding period.

Bryant et al. (2010) reported no differences in DMI when feeding 0, 100, or 200 mg/steer daily of RAC during the last 28 d of RAC being fed, which is consistent with previous research when feeding 200 mg of RAC (Abney et al., 2007; Gruber et al., 2007; Boler et al., 2012; Pyatt et al., 2013). Furthermore, Edenburn et al. (2016) and Arp et al. (2014) fed 400 mg/steer daily of RAC for 28 or 30 d and they observed no differences in DMI when compared with steers fed no RAC. Alternatively, Arp et al. (2014) and Avendaño-Reyes et al. (2006) reported a 1.6 and 1.7% decrease in DMI when steers were fed 300 mg of RAC compared with steers not fed RAC, which is in agreement with results reported by Quinn et al. (2016). In contrast, feeding 300 mg of RAC had no effect on DMI (Boler et al., 2012; Pyatt et al., 2013; Hales et al., 2016).

Abney et al. (2007) reported a linear increase in G:F as RAC dose increased. During the time RAC was being fed, these authors reported improvements of 19.2 and

25.8% when steers were fed 100 and 200 mg of RAC daily compared with steers not fed RAC. To a lesser extent, Pyatt et al. (2013) observed 9.7 and 16.4% improvements in G:F when steers were fed 100 and 200 mg of RAC/steer daily. Bohrer et al. (2014) fed 300 mg of RAC/steer daily and they reported a 16.8% improvement in G:F compared with steers fed no RAC, which would agree with Arp et al. (2014) who reported a 23.1% improvement in G:F when feeding 300 and 400 mg of RAC/steer daily. Feed efficiency was improved by 16.0% when steers were fed 400 mg of RAC/steer daily compared with steers fed no RAC in the Freedom of Information Summary (FDA, 2009).

Increasing RAC dose linearly increased HCW in the meta-analysis of Pyatt et al. (2013). These authors reported that HCW was 3.1, 6.1, and 9.2 kg greater for steers fed RAC (100, 200, and 300 mg/steer daily) compared with steers not fed RAC. Similarly, Gruber et al. (2007) and Bryant et al. (2010) reported an increase in HCW of 6.0 and 6.3 kg when steers were fed 200 mg of RAC/steer daily. Furthermore, feeding 200 mg of RAC/steer daily resulted in a 13.2 kg increase in HCW compared with steers not fed RAC (Boler et al., 2012). Although not significant, Hales et al. (2016) reported a 6.0 kg increase in HCW when steers were fed 300 mg of RAC daily. Similarly, feeding 300 mg of RAC/steer daily increased HCW by 8.1 kg when compared with steers not fed RAC (Quinn et al., 2016). Furthermore, Boler et al. (2012) fed 300 mg of RAC/steer daily and they observed a 14.9 kg increase in HCW compared with steers not fed RAC, and Avendaño-Reyes et al. (2006) reported a 13.6 kg increase in HCW. Similar improvements in HCW have been observed when feeding 400 mg of RAC/steer daily. Arp et al. (2014) noted a 6.3 kg increase in HCW whereas Edenburn et al. (2016) observed a 7.0 kg increase in HCW when feeding 400 mg of RAC/steer daily.

Ractopamine hydrochloride supplementation in beef finishing diets and the subsequent effects on dressing percent have been inconsistent based on published data. Dressing percent is variable when RAC is fed, likely due to the differences in gut fill (Watson et al., 2013) when live final BW are taken. Additionally, the time of weighing, feed intake, and environmental factors all have an effect on live BW, which can influence dressing percent. Pyatt et al., (2013) reported a linear increase in dressing percent as RAC dose increased. Furthermore, Bryant et al., (2012) noted a 0.46% unit increase in dressing percent when steers were fed 200 mg of RAC daily compared with steers not fed RAC. Similarly, Quinn et al. (2016) and Hales et al. (2016) observed 0.35 and 0.91% unit increases in dressing percent when feeding 300 mg of RAC/steer daily compared with steers fed no RAC. Alternatively, previous data has suggested that RAC supplementation has no effect on dressing percent (Gruber et al., 2007; Scramlin et al. 2010; Bohrer et al., 2014; Edenburn et al., 2016).

The effects of RAC dose has no effect on marbling score, fat thickness, and calculated yield grade (Griffin et al., 2009; Scramlin et al., 2010; Boler et al., 2012; Bryant et al., 2012; Edenburn et al., 2016; Hales et al., 2016). In contrast, Pyatt et al. (2013) reported a linear decrease in marbling score as RAC dose increased. Furthermore, Arp et al. (2014) and Quinn et al. (2016) reported a decrease in marbling score when steers were fed 300 mg of RAC compared with steers not fed RAC. When steers were provided 100 mg of RAC daily no differences were observed in LM area when compared with steers fed no RAC (Abney et al., 2007; Bryant et al., 2012). However, feeding 200 mg of RAC/steer daily increased LM area compared with steers not fed RAC (Abney et al., 2007; Boler et al., 2012; Bryant et al., 2012). Similarly, Boler et al. (2012) and Quinn

et al. (2016) observed an increase in LM area when feeding 300 mg of RAC/steer daily compared with steers not fed RAC, whereas Hales et al. (2016) observed no difference in LM area when feeding 300 mg of RAC/steer daily. Furthermore, Arp et al. (2014) noted an increase in LM area when feeding 400 mg of RAC/steer daily compared with steers fed no RAC. Previous data would suggest that RAC dose has no effect on USDA quality grade distribution (Abney et al., 2007, Boler et al., 2012; Bryant et al., 2012; Edenburn et al., 2016; Hales et al., 2016). A summary of differing ractopamine dose on live final BW and HCW is presented in Table 1.1.

Conclusions

Backgrounding systems in Nebraska provide an opportunity for cattle to utilize the abundant supply of forage resources while increasing frame size and placing heavier weight cattle into the feedlot. This strategy not only spreads out the distribution of cattle being harvested throughout the year, but also reduces the number of total days needed in the feedlot. Research evaluating intensive and extensive systems have been well studied; however, research evaluating the effects of placement weight into the feedlot on growth performance is limited.

The use of feed additives, such as the monensin and tylosin, have been well studied and in most instances has shown an improvement in feed efficiency when provided in the finishing diet. Previous research has shown that natural plant extracts have exhibited similar antimicrobial activity as antimicrobial feed additives. Providing these products in combination with ionophores may produce a synergistic effect that enhances animal performance.

Beta-adrenergic agonists, such as ractopamine hydrochloride, have been approved in beef cattle to be fed the last 28-42 days of the finishing period since 2003. Feeding ractopamine hydrochloride improves feed efficiency, live final BW, and HCW when fed prior to harvest. However, no published data exist evaluating the effects of feeding ractopamine hydrochloride for less than 28 days due to FDA restrictions.

Therefore, the objectives of these experiments were to: 1) to determine how age and BW of steers at feedlot entry effects DMI, ADG, and feed efficiency over the finishing period, 2) evaluate the effects of NEXT ENHANCE essential oils on performance and carcass characteristics of steers fed finishing diets with or without monensin plus tylosin, and 3) evaluate the effects of RAC dose and duration of RAC feeding on growth performance and carcass characteristics of finishing steers.

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TABLE

Table 1.1. Effect of different essential oils on steer feedlot growth performance

Variable:	DMI, kg/d	ADG, kg	G:F
<i>Study</i>			
Meyer et al., 2009 ¹	12.1	1.76	0.145
Meyer et al., 2009 ²	12.0	1.81	0.151
Meyer et al., 2009 ³	12.0	1.81	0.151
Yang et al., 2010a ⁴	7.78	1.68	0.219
Yang et al., 2010a ⁵	8.42	1.75	0.209
Yang et al., 2010a ⁶	8.17	1.65	0.206
Yang et al., 2010a ⁷	7.69	1.64	0.218
Bittner 2012 ⁸	10.1	1.78	0.176
Bittner 2012 ⁹	10.2	1.79	0.176
Westerhold et al., 2013 ¹⁰	12.9	1.41	0.111
Westerhold et al., 2013 ¹¹	12.7	1.41	0.112
Westerhold et al., 2013 ¹²	12.3	1.36	0.111
Westerhold et al., 2013 ¹³	11.8	1.24	0.105

¹Control no feed additives²Essential oil mixture fed at 1.0 g/steer daily³Experimental essential oil mixture fed at 1.0 g/steer daily⁴Control no feed additives⁵ Cinnamaldehyde fed at 400 mg/steer daily⁶ Cinnamaldehyde fed at 800 mg/steer daily⁷ Cinnamaldehyde fed at 1600 mg/steer daily⁸Control no feed additives⁹NEXT ENHANCE fed at 300 mg/steer daily¹⁰Control no feed additives¹¹NEXT ENHANCE fed at 150 mg/steer daily¹²NEXT ENHANCE fed at 300 mg/steer daily¹³NEXT ENHANCE fed at 600 mg/steer daily

Table 1.2. Effect of production system (calf-fed, short yearling, and long yearling) on feedlot growth performance

Variable:	DMI, kg			ADG, kg/d			G:F		
System:	Calf-fed	Short Yearling	Long Yearling	Calf-fed	Short Yearling	Long Yearling	Calf-fed	Short Yearling	Long Yearling
<i>Study</i>									
Adams et al., 2010	9.12	11.37	13.15	1.60	1.86	1.94	0.179	0.164	0.147
Griffin et al., 2007	9.71	-	13.89	1.73	-	2.06	0.178	-	0.150
Sainz and Paganini 2004	8.58	10.33	12.42	1.22	1.44	1.54	0.142	0.140	0.124
Guretzky et al., 2006	8.4	10.7	13.1	1.3	1.7	1.8	0.16	0.16	0.14
Lancaster et al., 2014	8.49	-	11.52	1.52	-	1.71	0.178	-	0.157

Table 1.3. Effect of ractopamine hydrochloride dose (mg/hd/d) on live final BW and HCW over cattle fed 0 mg/hd/d of ractopamine hydrochloride

Variable:	Live Final BW, kg				HCW, kg			
Dose:	100	200	300	400	100	200	300	400
<i>Study</i>								
Avendano-Reyes et al., 2006	-	-	10.6	-	-	-	13.6	-
Abney et al., 2007	5.9	9.4	-	-	4.1	6.9	-	-
Gruber et al., 2007	-	7.3	-	-	-	5.5	-	-
Strydom et al, 2009	-	-	14.1	-	-	-	7.0	-
Bryant et al., 2010	3.6	6.0	-	-	1.0	6.3	-	-
Boler et al., 2012	-	14.8	14.6	-	-	13.2	14.9	-
Pyatt et al., 2013	3.4	6.8	10.2	-	3.1	6.1	9.2	-
Arp et al., 2014	-	-	-	-	-	-0.6	3.9	6.3
Bohrer et al., 2014	-	-	8.0	-	-	-	8.0	-
Edenburn et al., 2016	-	-	-	7.0	-	-	-	7.0
Hales et al., 2016	-	-	6.0	-	-	-	6.0	-
Quinn et al., 2016	-	-	9.3	-	-	-	8.1	-

**CHAPTER II. PREDICTING FEEDLOT GROWTH PERFORMANCE OVER
THE FEEDING PERIOD UTILIZING STEER AGE AND BODY WEIGHT**

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Abstract

Typically, mean growth performance is known for the entire feeding period and is used to formulate feedlot finishing diets. A more accurate way for formulating diets would be to know performance (DMI and ADG) at the beginning of the feeding period when requirements are greatest. A pooled-analysis (2002-2015) of University of Nebraska-Lincoln research pen performance examined how steer age and feedlot entry BW affects growth performance over the finishing period. For data analysis, pens were divided into 3 subclasses when they started the finishing period, which included: 1) calf-fed (entering the feedlot at receiving), 2) short yearling (grazed during winter and entering the feedlot in May), and 3) long yearlings (grazed during the winter and summer and entering the feedlot in September). Furthermore, within each steer age class, pen means were grouped based upon initial BW (226.8 to 544.3 kg, in 45.4 kg increments) when starting the finishing diet. There were 1,002 pens of calf-feds, 1,114 pens of short yearlings, and 435 pens of long yearlings. As initial BW increased, dry matter offered (DMO) (kg/d) for the whole feeding period increased quadratically ($P = 0.01$) in calf-fed steers and averaged 10.4 kg/d. However, in short yearlings, DMO increased linearly ($P = 0.01$) as initial BW increased, with DMI averaging 11.7 kg/d. Likewise, DMO increased linearly ($P = 0.01$) as initial BW increased for long yearlings and averaged 12.9 kg/d. For all age groups and initial weight class of steers, calculating DMO as a percent of current BW was relatively constant over the entire feeding period with a range of 2.2 to 2.6%. Intake as a percent of current BW was greatest early (2.7%) in the finishing period and decreased linearly ($P = 0.01$) as days on feed increased (2.3%). A quadratic increase ($P = 0.03$) in ADG was observed in calf-feds as initial BW increased. No differences (P

≥ 0.60) in ADG were observed for short yearlings due to initial BW. However, ADG increased linearly ($P = 0.01$) as initial BW increased for long yearlings. As heavier cattle were placed within each age group, G:F decreased linearly ($P = 0.01$). Evaluating intake as a percent of current BW reduces variation due to steer age and BW; however, as days on feed increases, intake as a percent of current BW decreases. Predicting intake and growth performance over the entire feeding period is dependent upon steer age and initial weight when starting the finishing diet.

Key Words: cattle size, feedlot performance, intake

Introduction

The ability to predict feedlot growth performance over the feeding period is critical when determining nutritional requirements of animals at different stages of growth. For diet formulation, accurately predicting DMI and ADG at the beginning of the feeding period is more critical than overall average performance for the entire feeding period, as requirements for protein are greatest at the beginning of the feeding period. Also, the capability for feedlot managers to predict feedlot performance of varying ages and BW of cattle entering the feedlot is valuable for marketing decisions.

There are numerous factors that affect growth performance during the finishing period such as diet, age, temperature, weather, etc. A common practice today is backgrounding cattle on forages, such as crop residue or pastureland, for a certain period of time before starting the finishing phase. In Nebraska, the abundant availability of crop residues, such as cornstalks, allows producers to take spring born calves and background them during winter months at a relatively inexpensive cost of gain. In the southern

plains, backgrounding calves on wheat pasture is common in the winter months (Winterholler et al., 2008). Furthermore, grazing pastureland allows producers to further prolong the backgrounding period and to add weight to the animal. Previous research has evaluated the effects of different backgrounding systems on finishing performance (Adams et al., 2010; Griffin et al., 2007); however, research evaluating the effects of cattle age and BW when entering the feedlot is limited (Reinhardt et al., 2009). Therefore, the objective of this pooled analysis was to determine how age and BW of steers at feedlot entry affects DMO, ADG, and feed efficiency over the finishing phase.

Materials and Methods

A pooled-analysis from studies conducted at the University of Nebraska-Lincoln Agricultural Research and Extension Center research feedlot, near Mead, NE, examined the effects of steer age and initial BW on feedlot growth performance in studies conducted from 2002-2015. All facilities and procedures were approved by the University of Nebraska Institutional Animal Care and Use Committee. In all studies, the University of Nebraska purchased spring born steer calves in the fall for research trials. After an initial receiving period, steers were sorted based on BW into 3 different management systems. The heaviest steer calves were finished as calf-feds, intermediate weight steers were finished as short yearlings, and the lightest steer calves were finished as long yearlings. For data analysis, pens were divided into 3 subclasses based on steer age (calf-fed, short yearling, or long yearling) when they started the finishing diet. Calf-feds were defined as starting the finishing diet in the fall, usually November, and then finished the following spring, typically May. Following an approximate 21 d receiving period, all calf-feds were vaccinated, given an implant, and placed on feed. Average

initial BW for calf-feds was 313 kg (SD = 31 kg). Short yearlings were vaccinated and grazed corn residue or were grown in dry-lot on forage based diets from November to April, and then started on the finishing diet in May and harvested in September or October. Short yearlings had an initial BW of 372 kg (SD = 36 kg). During the wintering period short yearlings were grazed on corn residue and then drylotted in feedlot pens during the spring time. Long yearlings were vaccinated and backgrounded from November to April similar to short yearlings, grazed pasture from May to September, and then started the finishing period in October and were harvested in January or February. Average initial BW for long yearlings was 410 kg (SD = 47 kg). Furthermore, within each steer age class, pen means were grouped based upon initial BW (226.8 to 544.3 kg, in 45.4 kg increments) when starting the finishing diet. The data set included 1,002 pens of calf-feds, 1,144 pens of short yearlings, and 435 pens of long yearlings. In total, the data set included 93 experiments (36 calf-feds, 38 short yearlings, and 19 long yearlings) consisting of 23,438 steers.

In all studies, steer performance included dry matter offered (DMO), ADG, and G:F. Explanation for using DMO instead of DMI in the current analysis is that feed refusals were not accounted for within each experiment, only the amount of feed that was delivered to the feed bunk was used. The performance period included the adaptation period, in which steers were transitioned to the finishing diet. A high concentrate finishing diet was fed in all studies. Prior to initiation for each trial, steers were limit fed a diet at 2% BW to minimize variation in gastrointestinal fill (Watson et al., 2013). In each trial, steers were weighed two consecutive days (d 0 and 1) to establish initial BW. Feed bunks were assessed daily at approximately 0600 h for presence of feed. Bunks

were managed daily so that only trace (≤ 0.2 kg) amounts of feed were present in the bunk at time of feeding. Cattle were fed once daily between 0700 and 0900. Steers had *ad libitum* access to fresh clean water and their respective diet.

Weekly DMO during the feeding period, as a percentage of current BW, was calculated for each pen in the data set. Using initial pen BW and carcass adjusted ADG over the entire feeding period, weekly pen BW were calculated by increasing carcass-adjusted ADG by 0.002984668 kg/d up to 50% of DOF and then decreasing carcass-adjusted ADG by 0.002984668 kg/d beyond 50% DOF (Wilken et al., 2015). Body weight gain for each pen was calculated each week and added to pen BW from the previous week. Finally, weekly DMO for each pen was divided by the pen BW for the same week and DMO as a percent of current BW was determined.

Individual carcass data were collected on all steers, and growth performance was calculated from carcass-adjusted final BW. Carcass-adjusted final BW was determined by using HCW adjusted to a common dressing percentage (63%). All studies were conducted under similar management practices at the beef research feedlot. Performance data from each pen of steers were used in the pooled-analysis. Initial BW class, within each steer age category, was used as the experimental unit. Experiments were weighted by the number of initial BW classes within each experiment to prevent artificial responses from experiments that consisted of only one or two initial BW classes. Linear and quadratic regression coefficients were calculated using the mixed procedures of SAS (SAS Institute, Inc., Cary, N.C.). The significance of the linear and quadratic coefficients was also tested for each response variable using the mixed procedures of SAS.

Experiment was included in the model as a random effect. The interaction between initial BW class and finishing diet was tested, based on byproduct inclusion level, and was not significant ($P > 0.10$); therefore, the effect of finishing diet was removed from the analysis. Differences were considered significant when $P \leq 0.05$. Linear regression was used to examine the relationship between growth performance variables and percentage of days on feed. Data were analyzed using the REG and GLIMMIX procedures of SAS. For each age group of cattle, data were plotted with each pens percentage of days on feed as the independent variable on the x axis and growth performance variable on the y axis, which were DMO, G:F, DMO as % of current body weight. Standard errors of the slope and intercept of the lines are reported.

Results and Discussion

Dry matter offered increased linearly ($P < 0.01$; Table 2.1) as initial BW class increased. Within cattle class (calf-fed, short yearling, or long yearling), as initial BW class increased, DMO (kg/d) increased quadratically ($P = 0.01$; Table 2.2) in calf-fed steers and averaged 10.4 kg/d over the entire feeding period. However, in short yearlings, DMO increased linearly ($P < 0.01$) as initial BW class increased, with DMO averaging 11.7 kg/d. Likewise, DMO increased linearly ($P < 0.01$) as initial BW class increased for long yearlings and averaged 12.9 kg/d. Hicks et al. (1990) evaluated DMI records, based on initial BW entering the feedlot and they concluded that as initial BW increased, DMI increased, which is supported by the current analysis. Similarly, Hicks et al. (2015) compiled weekly DMI data from a commercial feedlot in the Southern Great Plains and these authors concluded that DMI was greater for steers with heavier initial weights when entering the feedlot compared to lighter weight steers. This is further supported by

Saubidet and Verde (1976) which concluded that DMI increases as animal age increases. Numerous studies have reported lower daily DMI with younger calves compared to older calves (Myers et al., 1999; Story et al., 2000; Schoonmaker et al. 2002; Sainz and Vernazza Paganini 2004). Furthermore, Adams et al. (2010) compared calf-fed, short yearling, and long yearling production systems for the same genetic group of steers and they concluded that DMI was greatest for long yearlings compared to the other two production systems. Furthermore, Griffin et al. (2007) made the comparison between calf-fed and long yearlings utilizing a dataset that consisted of 1,106 steers. In this comparison, at weaning time the heavier steers were sorted off and entered the feedlot and finished as calf-feds and the lighter steers entered an extensive long yearling system. Dry matter intake during the finishing period was greater for long yearlings compared with calf-fed. The differences observed in DMO in the current study are quite similar to that of previous research which suggest that yearling cattle eat more than calf-feds, which could be partially attributed to the fact that the capacity of the digestive tract is greater for yearling cattle.

Changes in DMO over the feeding period as a percentage of days on feed is shown in Figure 2.1 for calf-fed, short yearling, and long yearling. Differences in level of DMO throughout the feeding period differs between calf-feds, short yearling, and long yearlings. Dry matter offered increased for the first 10 to 20% of the feeding period and then plateaued for the remainder of the feeding period for both calf-feds and short yearlings. For long yearlings, DMO increased for the first 50 to 60% of the feeding period and then declined for the final 40 to 50% of the feeding period. Similarly, data from Zinn (1987) would suggest that DMI throughout the feeding period differs between

calf-feds and yearlings, with intakes being consistently higher for yearlings compared to calf-feds during the finishing period. Furthermore, Hicks et al. (1990) evaluated the effects of DMI over the feeding period for both calf-feds and yearlings. These authors concluded that DMI intake increased linearly for the first 40 to 50 d, plateaued for approximately 40 d, then decreased the final 40 d for yearlings. Conversely, they reported that DMI of calf-feds increased for about the first 70 d and plateaued for the remaining 100 d.

The one variable that is measured routinely and accurately over the entire feeding period is DMO. While ADG can be modelled for the feeding period, DMO is known. Overall, DMO was quite variable for all age groups of steers with a range of 9.7 to 14.1 kg/d being observed. However, when calculating DMO as a percent of current BW (Table 2), DMO was relatively constant over the entire feeding period with a range of 2.2 to 2.6% for all age groups and initial BW class of steers. Mean DMO increased linearly ($P < 0.01$) as initial BW increased for all classes of cattle; however, when DMO was expressed as a percent of current BW it decreased linearly ($P < 0.01$). Furthermore, expressing DMO as a percent of current BW within each class of cattle (calf-feds, short yearlings, and long yearlings) decreased linearly ($P < 0.01$) as initial BW increased for. Dry matter offered as a percent of current BW over the feeding period is presented in Figure 2.2. Intake as percent of current BW was greatest early in the finishing period and decreased linearly ($P < 0.01$) as percentage of days on feed increased. Throughout much of feeding period, DMO as percent of current BW was lowest for calf-fed steers. These data suggest that as initial BW increases, DMO increases, and this would be the general perception of many producers; however, when intake is calculated as a percent of current

BW it decreases as steer initial BW increases. Furthermore, as initial BW increased, DMO expressed as a percentage of mean feeding BW decreased linearly for calf-feds, short yearlings, and long yearlings. These findings would agree with the commercial data of Hicks et al. (2015) which would suggest that DMI as a percentage of mean BW decreased linearly as initial BW increased. In the current study, average DMO (kg/100 kg BW) for calf-feds, short yearlings, and long yearlings were 2.22, 2.34, and 2.35 kg/100 kg BW, respectively. Interestingly, when making this calculation with data from Griffin et al. (2007) they observed a similar response in DMI (2.22 kg/100 kg BW) in calf-feds; however, a greater DMI was observed in yearlings (2.63 kg/100 kg BW). Additionally, Adams et al. (2010) reported daily DMI of 2.22, 2.33, and 2.43 kg/100 kg BW for calf-feds, short yearlings, and long yearlings, respectively.

As initial BW class increased across all classes of cattle, ADG increased linearly (Table 2.1; $P < 0.01$). However, a quadratic increase ($P = 0.03$) in carcass-adjusted ADG was observed in calf-feds as initial BW class increased (Table 2.2). Numerically, ADG was least for calf-fed steers that started the finishing phase at an initial BW class of 227 kg (1.70 kg/d) and greatest for steers weighing 363 kg (1.80 kg/d). No differences ($P \geq 0.60$) in carcass-adjusted ADG were observed for short yearlings, which suggest that initial BW when starting the finishing diet had no effect on ADG throughout the finishing phase within a short yearling system. However, carcass-adjusted ADG increased linearly ($P = 0.05$) as initial BW class increased for long yearlings. Carcass-adjusted ADG was 1.71 kg/d for steers starting the finishing diet at 318 kg compared to 1.82 kg/d for steers weighing 544 kg. In agreement with our findings, Zinn et al. (2008) reported that as initial BW increased, ADG increased linearly for steers. Commercial feedlot data of

Hicks et al. (2015) reported ADG being greater for steers with a heavier initial weight compared with steers starting at a lighter weight. Similarly, Adams et al. (2010) who reported ADG being lowest for calf-feds, intermediate for summer yearlings, and greatest for fall yearlings. Griffin et al. (2007) reported similar findings with calf-feds (1.73 kg/d) gaining less than long yearlings (2.06 kg/d). Schoonmaker et al. (2002) demonstrated that ADG was lowest for steers starting the finishing diet at 111 d of age, followed by steers that were placed in the feedlot at 202 d of age, and greatest for yearling steers. Alternatively, Sainz and Vernazza Paganini (2004) compared calf-fed, short yearling, and long yearling systems and these authors concluded that ADG was not different between systems. However, there was a tendency for ADG to be 0.20 kg/d greater for long yearlings compared to calf-feds. Furthermore, Reinhardt et al. (2009) evaluated a dataset (15,631 steers) looking at how initial BW of calves entering the feedlot effects feedlot performance. Body weight groups were categorized as follows: ≤ 226 , 227 to 272, 272 to 317, 318 to 362, and ≥ 363 kg. These authors observed that steers entering the feedlot at heavier initial BW actually gained less than steers with lighter initial BW, which is contrary to our findings. Reinhardt et al. (2009) reported ADG being 1.60 kg/d for steers weighing ≤ 226 kg and for steers weighing ≥ 363 kg ADG was 1.46 kg/d. Comparing these results to our calf-feds, which were similar in initial BW when entering the feedlot, steers in our dataset weighing 227 kg gained 1.70 kg/d and those weighing 363 kg gained 1.80 kg/d. Reasons for these differences in ADG could partially be attributed to the fact that the steers in the Reinhardt et al. (2009) study were fed at 18 different feedlots. Therefore, different management strategies implemented amongst feedlots could explain

the differences observed in ADG. Whereas with our dataset, all steers were fed at the same feedlot and managed in a similar manner over the years.

Increasing initial BW class across all classes of cattle linearly (Table 2.1; $P < 0.01$) decreased feed efficiency (G:F). Furthermore, G:F decreased linearly ($P < 0.01$) as initial BW class for calf-fed steers increased (Table 2.2). Feed efficiency was 6.9% poorer for steers starting the finishing phase at an initial BW of 363 kg compared to steers weighing 227 kg for calf-feds. For short yearlings, G:F decreased linearly ($P < 0.01$) as initial BW class increased. Feed efficiency was 10.8% poorer for steers starting the finishing phase at 454 kg compared to 272 kg short yearlings. Lastly, G:F decreased linearly ($P < 0.01$) as initial BW class increased for long yearlings. Feed efficiency was 12.0% poorer for long yearlings starting the finishing phase at 544 kg compared to 318 kg. In agreement with our dataset, Hicks et al. (2015) demonstrated that G:F gets poorer as initial BW increases during the feeding period. Furthermore, Griffin et al. (2007) reported feed efficiency being 18.7% greater for calf-feds compared to long yearlings. Similarly, feed efficiency was greatest for calf-feds, intermediate for short yearlings, and poorest for long yearlings (Adams et al., 2010). Feed efficiency throughout the feeding period is presented in Figure 2.3. As the percentage of days on feed increased, poorer G:F was exhibited. Feed efficiency was greater for calf-feds than both short and long yearlings over the feeding period. These data support what many producers already know, that bigger cattle are less efficient (poorer G:F) than lighter cattle. Explanation for poorer feed efficiency in heavier cattle, such as yearlings, is that much of the skeletal growth and muscle accretion occurs during the growing phase. The loss in efficiency is

because it takes less energy to gain 1 kg of muscle than 1 kg of fat (NRC, 1996). This common observation holds true within cattle age group though as well.

In conclusion, delaying the time (i.e., increasing age) in which steers start the finishing phase results in poorer feed efficiency. Evaluating DMO as a percent of current BW reduces variation due to steer age and BW. As percentage of days on feed increases, intake as a percent of current BW decreases. These data suggest that DMO as a percent of current BW varies from 2.5 to 2.8% for calf-feds, short yearlings, and long yearlings when entering the feedlot. Predicting intake and growth performance over the entire feeding period is critical for producers to meet the nutritional requirements of the animal at certain stages of growth and varies depending on steer age and BW when started on the finishing diet.

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Table 2.1. Effect of initial BW class when starting the finishing phase on steer growth performance.

Initial BW Class (kg)	227	272	318	363	408	454	499	544	SEM	Linear ¹	Quad ²
DMO, kg/d	10.3	10.6	11.0	11.5	12.1	12.6	12.8	13.5	0.2	<0.01	0.50
ADG, kg ³	1.70	1.72	1.73	1.74	1.80	1.82	1.77	1.81	0.02	<0.01	0.28
G:F	0.168	0.163	0.157	0.152	0.151	0.145	0.141	0.139	0.003	<0.01	0.30
DMO, % CBW ⁴	2.47	2.43	2.37	2.30	2.23	2.16	2.06	2.04	0.03	<0.01	0.32
DMO, kg/100 kg BW	2.45	2.40	2.35	2.29	2.22	2.16	2.05	2.03	0.03	<0.01	0.21

¹Linear contrasts for initial BW class.

²Quadratic contrasts for initial BW class.

³Calculated using carcass-adjusted final BW.

⁴Dry matter offered calculated as a percent of current BW (CBW) over the entire feeding period.

Table 2.2. Effect of initial BW class when starting the finishing phase on steer growth performance.

Initial BW Class (kg)	227	272	318	363	408	454	499	544	SEM	Linear ¹	Quad ²
<i>Calf-feds</i>											
DMO, kg/d	9.7	10.1	10.5	11.1					0.1	<0.01	0.01
ADG, kg ³	1.70	1.72	1.73	1.80					0.03	<0.01	0.03
G:F	0.175	0.171	0.165	0.163					0.002	<0.01	0.48
DMO, % CBW ⁴	2.33	2.28	2.22	2.17					0.02	<0.01	0.62
DMO, kg/100 kg BW	2.30	2.25	2.20	2.14					0.02	<0.01	0.51
<i>Short Yearlings</i>											
DMO, kg/d		11.0	11.4	11.7	12.0	12.5			0.2	<0.01	0.54
ADG, kg ³		1.74	1.74	1.74	1.75	1.77			0.06	0.60	0.79
G:F		0.158	0.154	0.149	0.145	0.141			0.004	<0.01	0.93
DMO, % CBW ⁴		2.51	2.43	2.35	2.29	2.20			0.03	<0.01	0.38
DMO, kg/100 kg BW		2.49	2.41	2.34	2.28	2.18			0.04	<0.01	0.45
<i>Long Yearlings</i>											
DMO, kg/d			11.5	12.1	12.7	13.3	13.5	14.1	0.3	<0.01	0.15
ADG, kg ³			1.71	1.73	1.82	1.83	1.78	1.82	0.08	0.05	0.13
G:F			0.150	0.144	0.144	0.138	0.134	0.132	0.005	<0.01	0.99
DMO, % CBW ⁴			2.55	2.48	2.39	2.32	2.23	2.20	0.05	<0.01	0.80
DMO, kg/100 kg BW			2.53	2.46	2.38	2.32	2.21	2.19	0.05	<0.01	0.65

¹Linear contrasts for initial BW class within steer age group.²Quadratic contrasts for initial BW class with steer age group.³Calculated using carcass-adjusted final BW.⁴Dry matter offered calculated as a percent of current BW (CBW) over the entire feeding period.

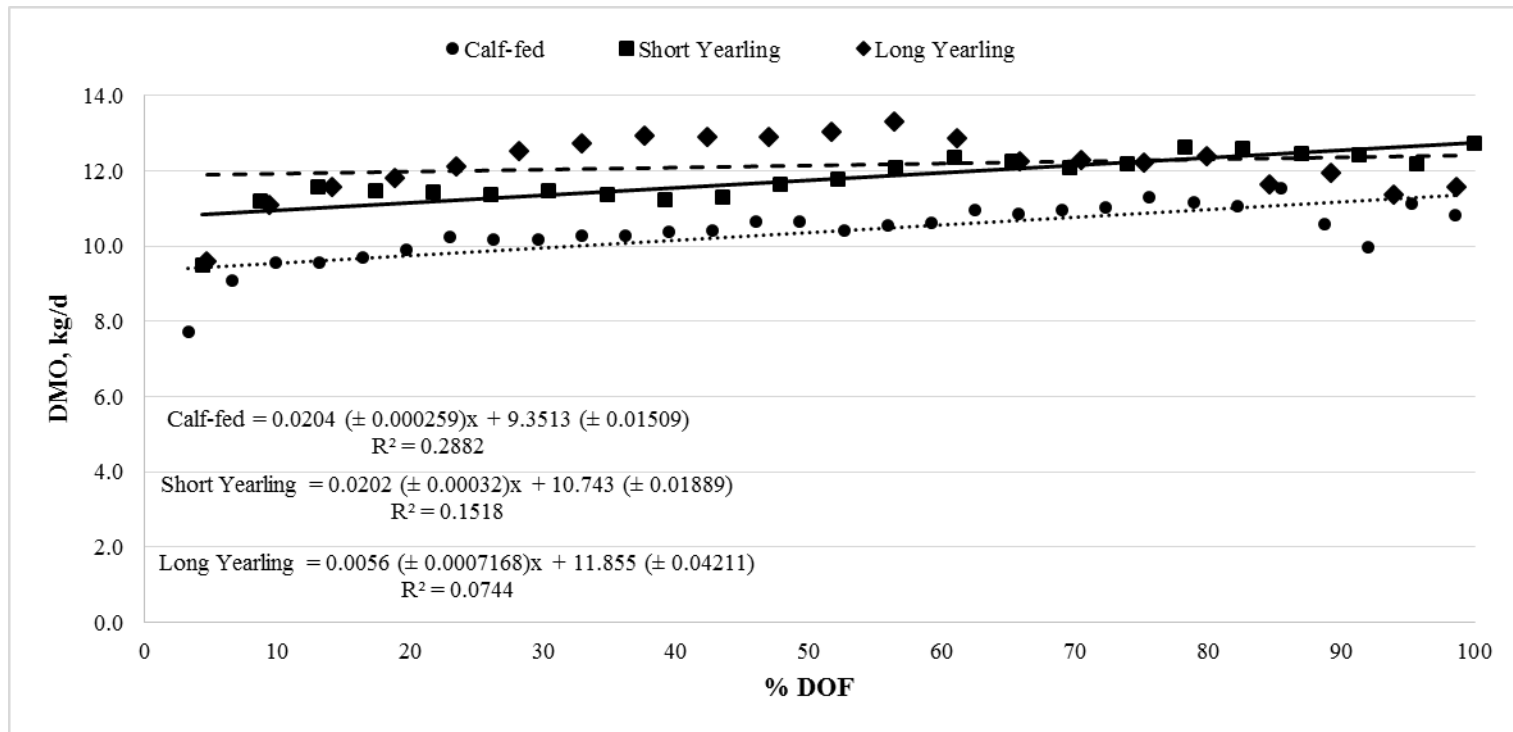


Figure 2.1. Dry matter offered for calf-fed, short yearling, and long yearling throughout the feeding period. The round dot line corresponds to calf-fed, solid line to short yearling, and dash line to long yearling.

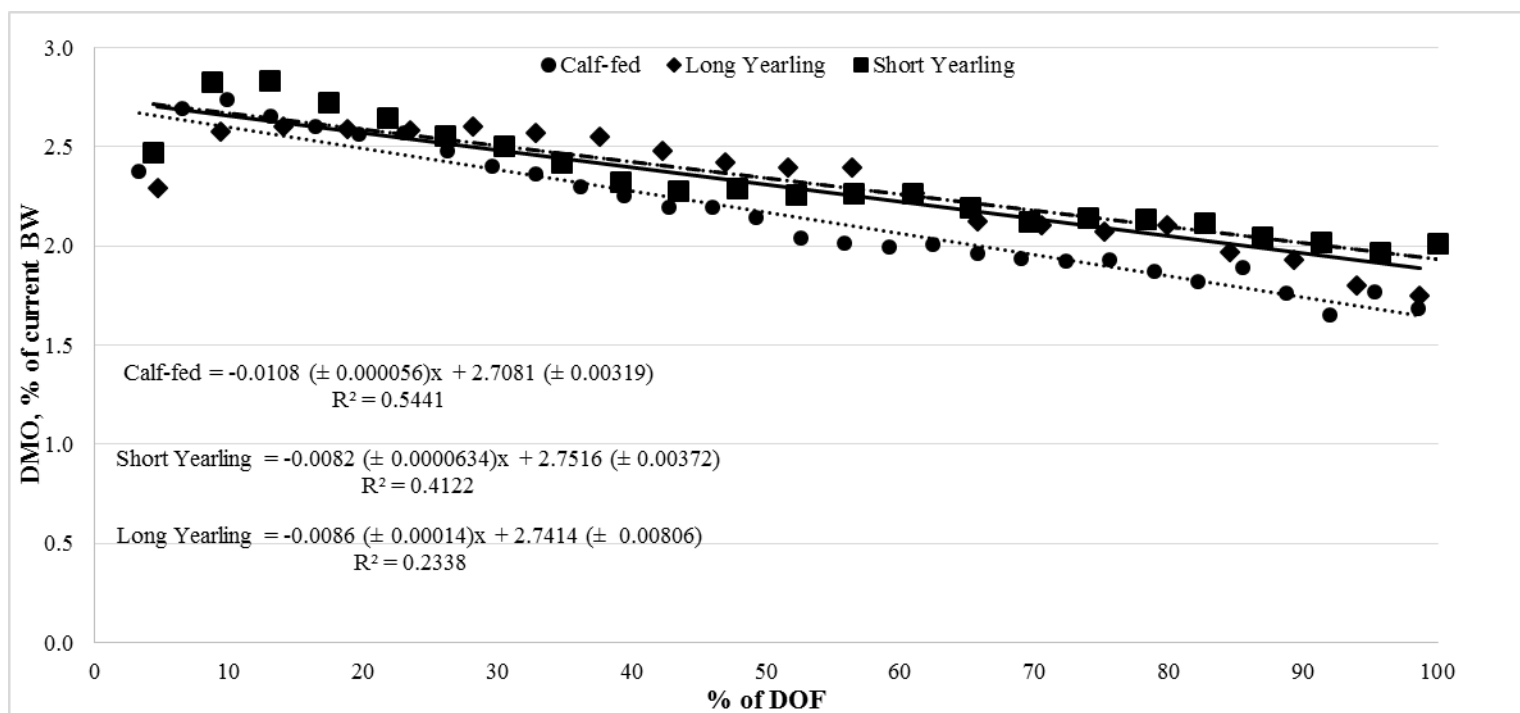


Figure 2.2. Dry matter offered as a percent of current BW for calf-fed, short yearling, and long yearling throughout the feeding period. The round dot line corresponds to calf-fed, solid line to short yearling, and dash line to long yearling.

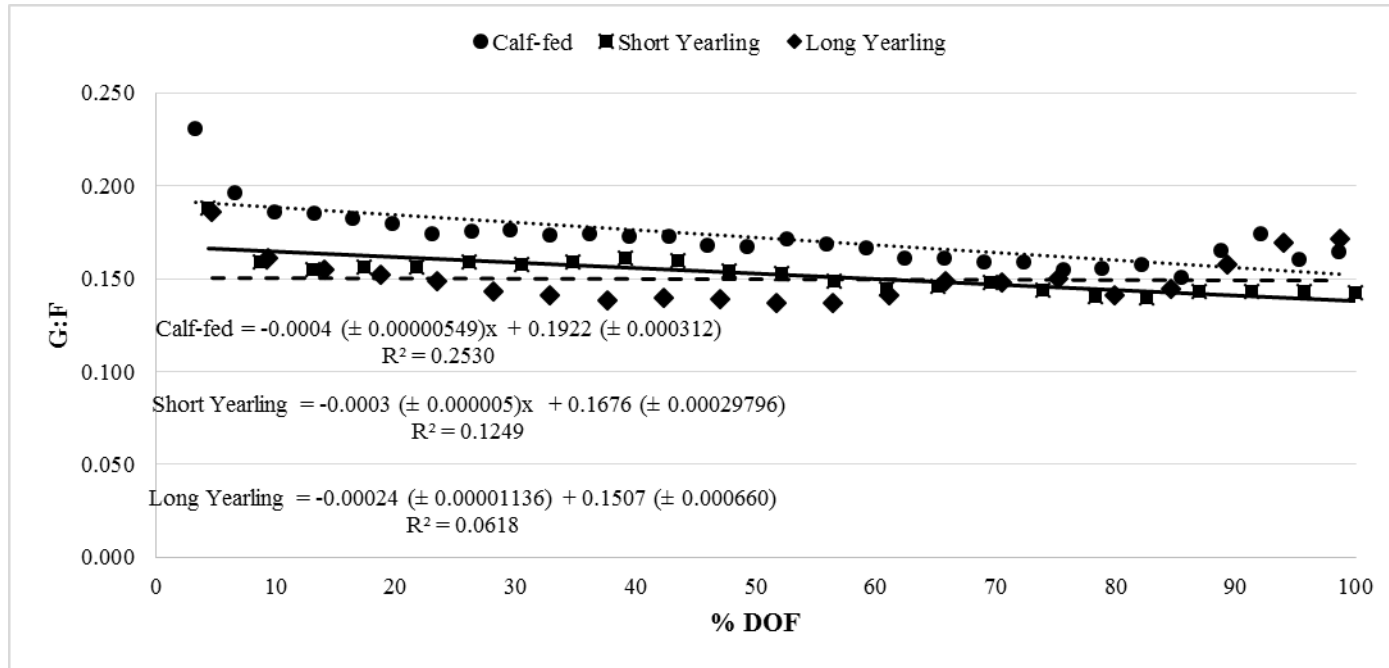


Figure 2.3. Change in feed efficiency for calf-fed, short yearling, and long yearling throughout the feeding period. The round dot line corresponds to calf-fed, solid line to short yearling, and dash line to long yearling.

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**CHAPTER III. EFFECTS OF ESSENTIAL OILS IN FINISHING DIETS, WITH
OR WITHOUT MONENSIN AND TYLOSIN, ON STEER PERFORMANCE AND
CARCASS CHARACTERISTICS**

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Abstract

Three feedlot finishing experiments were conducted evaluating the effects of NEXT ENHANCE 300 (EO) and monensin/tylosin (MT) on steer performance, carcass characteristics, and liver abscesses in finishing diets. In Exp. 1, 400 calf-fed steers (BW = 295; SD = 29 kg) were utilized in a randomized block design using a 2 x 2 factorial treatment structure. Factors included the presence or absence of EO and presence or absence of MT resulting in 4 treatments: 1) control, no additives (CON); 2) EO; 3) MT; and 4) EO plus MT (EOMT). Essential oils were included at 300 mg/steer daily, monensin at 360 mg/steer daily and tylosin at 90 mg/steer daily. There were no MT x EO interactions ($P \geq 0.46$) for finishing performance or carcass characteristics ($P \geq 0.10$). There was a tendency ($P = 0.07$) for increased ADG for steers fed MT, while feeding EO had no effect ($P = 0.85$). In diets containing MT, a 3.9% improvement in G:F ($P < 0.01$) was observed but when feeding EO G:F was not different ($P = 0.87$) among treatments. Incidence of liver abscesses decreased by 45.7% in steers fed MT ($P < 0.01$), when compared to steers not fed MT. In Exp. 2, 360 calf-fed steers (BW = 297; SD = 28 kg) were used to evaluate the effects of EO dose in finishing diets containing 360 mg/steer daily of monensin and 90 mg/steer daily of tylosin. Treatments consisted of 0, 75, 150, 225, or 300 mg/steer daily of EO. Increasing EO dose linearly ($P = 0.04$) decreased DMI, but ADG was not different ($P \geq 0.77$) among treatments. Gain efficiency linearly ($P = 0.02$) increased as dose of EO increased. A 4.4 and 3.8% improvement in G:F was observed when feeding EO at 225 and 300 mg/steer daily, respectively, compared to steers fed 0 mg/steer daily EO. In Exp. 3, 288 yearling steers (BW = 449; SD = 23 kg) were used to evaluate the effects of EO concentration in finishing diets containing MT at

doses of 360 and 90 mg/steer daily. Treatments consisted of 0, 16.5, 33.1, or 49.6 mg/kg of EO. Increasing EO concentration did not effect ($P \geq 0.60$) DMI, ADG, or G:F.

Results from these studies indicate that feeding NEXT ENHANCE 300 essential oils in finishing diets has variable impacts on animal performance.

Key Words: essential oils, feedlot cattle, liver abscesses

Introduction

The use of monensin (Rumensin; Elanco Animal Health, Greenfield, IN), an ionophore antibiotic, has been widely accepted in feedlots since its approval in 1975. Previous research with the addition of monensin in diets has shown its ability to reduce DMI (Goodrich et al., 1984; Duffield et al., 2012), improve G:F (Potter et al., 1985), reduce feed intake variation (Stock et al., 1995), and reduce acidosis (Erickson et al., 2003).

Tylosin (Tylan; Elanco Animal Health) has been approved for the prevention and control of liver abscesses in beef cattle caused by *Fusobacterium necrophorum* and *Trueperella pyogenes* (Nagaraja and Lechtenberg, 2007; Yassin et al., 2011). Feeding tylosin decreases liver abscesses, increases ADG, and improves G:F (Brown et al. 1973; Vogel and Laudert, 1994; Potter et al. 1995). Traditionally, monensin and tylosin are fed in combination. Feeding monensin plus tylosin reduces DMI (Stock et al., 1995; Meyer et al., 2009), increases ADG (Stock et al., 1995) and improves G:F (Stock et al., 1995; Meyer et al., 2009).

Essential oils are secondary plant metabolites that can be extracted from plant tissues with the use of steam distillation or organic-solvents (Wallace, 2004; Calsamiglia

et al., 2007). Secondary plant metabolites have been reported to have ruminal antimicrobial activity against gram-positive and gram-negative bacteria (Cowan, 1999). Studies conducted *in vitro* with essential oils have demonstrated decreases in the proportion of acetate to propionate during ruminal fermentation (Busquet et al., 2005). Feeding essential oils has been reported to reduce DMI (Yang et al., 2010b) and improve G:F (Benchaar et al., 2006; Meyer et al., 2009). However, few feedlot performance studies have been conducted to support these findings of improvement. Improving feed efficiency, with the use of essential oils, may be a viable alternative to the use of ionophores in the future. Therefore, the objective of these experiments were to evaluate the effects of NEXT ENHANCE essential oils on performance and carcass characteristics of steers fed finishing diets with or without monensin plus tylosin.

Materials and Methods

All facilities and procedures were approved by the University of Nebraska Institutional Animal Care and Use Committee. (IACUC Protocol #631)

Exp. 1

Four hundred British x Continental calf-fed steers (BW = 295; SD = 29 kg) were utilized in a randomized block design experiment. Steers were received at the University of Nebraska – Lincoln (UNL) Panhandle Research and Extension Center (PREC) feedlot (near Scottsbluff, Nebraska) in the fall of 2011 over a 3 day (d) period. Within 24 hours of arrival, cattle were processed and vaccinated with a modified live virus respiratory vaccine containing infectious bovine rhinotracheitis virus, bovine viral diarrhea virus I and II, parainfluenza-3, and bovine respiratory syncytial virus (Bovishield Gold 5; Zoetis,

Inc., Kalamazoo, MI), vaccinated with a *Clostridium chauvoei*, *C. septicum*, *C. novyi*, *C. sordellii*, *C. perfringens* types C and D bacterin toxoid (Vision 7; Merck Animal Health, De Soto, KS), vaccinated with a *Haemophilus somni* vaccine containing 3 inactivated *H. somni* isolates (Somubac; Zoetis, Inc.), treated for internal and external parasites with ivermectin paraciticide (Ivomec; Merial, Duluth, GA), and given an electronic and visual identification tag. On d 9, all steers were re-vaccinated with Bovi-Shield Gold 5, Somubac, and given an initial implant of Component TE-IS (16 mg of estradiol-17 β (E₂), 80 mg of trenbolone acetate (TBA), and 29 mg of tylosin tartrate; Elanco Animal Health). Steers were re-vaccinated on d 51 with a modified live virus respiratory vaccine containing infectious bovine rhinotracheitis virus, bovine viral diarrhea virus I and II, parainfluenza-3, and bovine respiratory syncytial virus (Express 5; Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO). Cattle were re-implanted with Component TE-S (24 mg of E₂, 120 mg of TBA, and 29 mg of tylosin tartrate; Elanco Animal Health) and re-vaccinated with Vision 7 on d 79. Prior to study initiation, steers were limit fed a 50% alfalfa, 35% corn silage, and 15% wet distillers grains plus solubles (WDGS; Colorado Agri Products, Bridgeport, NE) diet (DM basis) at 2% of BW for 7 d to minimize gut fill variation (Watson et al., 2013). Steers were individually weighed (Silencer Squeeze Chute; Moly Mfg. Inc., Lorraine, KS: scale readability \pm 0.45 kg) on d 0 and 1 to establish initial BW (Stock et al., 1983), blocked by d 0 BW, stratified within blocks (light = 258 kg, medium = 295 kg, heavy = 332 kg), and assigned randomly to 40 pens. Pens were assigned randomly to one of four treatments with 10 replications (i.e. pen) per treatment and 10 steers per pen. Light, medium, and heavy blocks consisted of 3, 5, and 2 replications, respectively.

A 2 x 2 factorial arrangement of treatments was used with one factor being the presence or absence of NEXT ENHANCE 300 (EO; Novus International, Inc., St. Charles, MO), and the other factor being presence or absence of monensin plus tylosin. The ingredients of EO are a proprietary blend of calcium carbonate, rice hulls, cinnamaldehyde, silica, mono and diglycerides of fatty acids, garlic oil, and mineral oil. Treatments included: control (CON) containing no additives, EO provided at 300 mg/steer daily, monensin plus tylosin provided at 360 and 90 mg/steer daily, respectively (MT), or EO provided at 300 mg/steer daily plus monensin (360 mg/steer daily) and tylosin (90 mg/steer daily; EOMT). Feed additives (monensin, tylosin, and EO) were provided daily via micro-machine (Model 271 Weigh and Gain Generation 7; Animal Health International, Greeley, CO). Steers were adapted to a common finishing diet over a 21 d period consisting of four adaptation diets. During the 21 d adaptation period, the amount of WDGS and supplement included in each adaptation diet was held constant at 25 and 6% (DM basis), respectively. The amount of corn was gradually introduced in the diet while replacing the amount of alfalfa hay and corn silage. On a DM basis, the first adaptation diet consisted of 32% corn silage, 20% alfalfa hay, and 17% dry-rolled corn (DRC) and was fed for 3 d. The second adaptation diet was fed for 4 d and consisted of 28% corn silage, 14% alfalfa hay, and 27% DRC (DM basis). The third adaptation step was fed for 7 d and consisted of 24% corn silage, 8% alfalfa hay, and 37% DRC (DM basis). The fourth and final adaptation diet was fed for 7 d and consisted of 20% corn silage, 4% alfalfa hay, and 45% DRC (DM basis). At the conclusion of the 21 d adaptation period, all steers were on the same basal diet (53% DRC, 25% WDGS, 16% corn silage, and 6% liquid supplement (DM basis); Table 3.1).

Steers were housed in open feedlot pens (7.3 x 54.9 m). Feed bunks were assessed daily at approximately 0600 h for presence of feed. Bunks were managed daily so that only trace amounts (≤ 0.2 kg) of feed were present in the bunk prior to the next feeding. Refused feed was removed as needed, weighed, sampled, and dried in a forced-air oven for 48 h at 60°C for DM determination (AOAC International, 1997; Method 930.15), to obtain accurate DMI. Cattle were fed once daily at 0800 h. Diets were mixed and delivered daily using a truck-mounted feed mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS; scale readability ± 0.91 kg). Individual ingredient samples were taken weekly and analyzed for DM content. Weekly ingredient samples were composited for the entire feeding period, with one sample of each ingredient being sent to a commercial laboratory (Servi-Tech Laboratories, Hastings, NE) for analysis of DM (AOAC, 930.150), NDF (ANKOM, 2006), CP (AOAC, 990.03), crude fat (Soxtec System HT 6), Ca, P, K, S, and starch (Xiong, et al., 1990). The nutrient composition for DRC used in this study was 84.9% DM, 9.6% NDF, 8.5% CP, 3.2% crude fat, $< 0.01\%$ Ca, 0.26% P, 0.30% K, 0.09% S, and 70.9% starch (DM basis). The WDGS used was 34.3% DM, 40.4% NDF, 30.2% CP, 11.0% crude fat, 0.05% Ca, 0.85% P, 1.12% K, 0.39% S, and 0.9% starch (DM basis). On a DM basis, the corn silage used was: 37.0% DM, 44.5% NDF 8.6% CP, 2.2% crude fat, 0.28% Ca, 0.23% P, 1.24% K, 0.10% S, and 29.0% starch.

Cattle from the medium and heavy BW blocks were harvested on d 141 and the light block on d 161 at Cargill Meat Solutions (Fort Morgan, CO). Carcass data were collected by Diamond T Livestock Services (Yuma, CO). Hot carcass weight and liver scores were recorded on day of harvest. Liver abscesses were scored using the Elanco

Liver Scoring System (Elanco, 2014): 0 (no abscesses), A (one or two small abscesses or abscess scars), or A+ (one or more large active abscesses). After a 48 h chill, LM area, marbling score, and 12th rib fat thickness were recorded. Yield grade was calculated (USDA, 1997) from the following formula: $2.50 + (6.35 \times \text{fat thickness, cm}) + (0.2 \times 2.5 [\text{KPH}]) + (0.0017 \times \text{HCW, kg}) - (2.06 \times \text{LM area, cm}^2)$. On d 141 and 161, individual live BW were collected and pencil shrunk 4% to calculate dressing percent. With the use of a common dressing percentage (63%), carcass adjusted final BW, ADG, and G:F were calculated from HCW.

Animal performance and carcass characteristics were analyzed as a 2 x 2 factorial using the MIXED procedure of SAS (SAS Inst., Inc., Cary, N.C) with pen being the experimental unit. The model included the effects of MT, EO, and MT x EO interaction. Block was treated as a fixed effect. Although there were no significant ($P \leq 0.05$) EO x MT interactions, the simple effect means are presented and main effects are discussed. Occurrences of liver abscesses were analyzed using the GLIMMIX procedure of SAS.

Exp. 2

In 2012, British x Continental crossbred calf-fed steers ($n = 360$; initial BW = 297; SD = 28 kg) were utilized in a randomized block design experiment at the UNL PHREC. Upon arrival at the feedlot, steers were vaccinated with Express 5 and given an electronic and visual identification tag. On d 80, all steers were re-vaccinated using BoviShield Gold 5 and treated with Ivomec. Calves were limit fed a 32% alfalfa, 32% WDGS, 32% DRC, 4% supplement diet (DM basis) at 2% BW for 7 d to eliminate gut fill variation. Steers were individually weighed and assigned randomly to one of 45 pens

using the same method as described in Exp. 1. Pens were assigned randomly to one of five treatments with 9 replications per treatment and 8 steers per pen. Light (263 kg), medium (298 kg), and heavy (332 kg) blocks consisted of 2, 4, and 3 replications, respectively.

A common basal finishing diet was used for all five treatments consisting of 65% DRC, 25% WDGS, 5% wheat straw, and 5% liquid supplement (DM basis; Table 3.1). Treatments consisted of EO doses of 0, 75, 150, 225, and 300 mg/steer daily, which were provided via micro-machine. Monensin and tylosin were provided via micro-machine in all treatments at 360 and 90 mg/steer daily. Steers were adapted to the finishing diet by feeding 3 adaptation diets for 7 d each. Alfalfa hay inclusion was gradually decreased from 30 to 10% (DM basis), while inclusion of DRC increased from 35 to 55% (DM basis) during the adaptation period. Wet distillers grains plus solubles, wheat straw, and supplement were included in all adaptation diets at 25, 5, and 5% (DM basis), respectively. The nutrient composition for DRC used in this study was 88.0% DM, 8.2% NDF, 8.1% CP, 2.4% crude fat, < 0.01% Ca, 0.28% P, 0.3% K, 0.09% S, and 74.1% starch (DM basis). The WDGS used was 30.0% DM, 27.1% NDF, 32.6% CP, 8.6% crude fat, 0.06% Ca, 0.82% P, 1.06% K, 0.50% S, and 1.8% starch (DM basis). On a DM basis, the wheat straw used was: 86.0% DM, 77.5% NDF 4.2% CP, 1.1% crude fat, 0.2% Ca, 0.06% P, 1.41% K, 0.09% S, and 1.0% starch. Bunk readings, feed delivery, feed refusals, and feed samples were collected according to the procedures described in Exp. 1.

Steers were implanted on d 0 with Revalor-XS (200 mg of TBA and 40 mg of E₂; Merck Animal Health). After 141, 169, and 174 d on feed, depending on BW block, cattle were weighed and transported to a commercial abattoir (Cargill Meat Solutions, Fort Morgan, CO.) and harvested. Live final BW, carcass characteristics, and carcass adjusted performance were collected the same as described for Exp. 1.

Performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS Inst., Inc.). Pen was the experimental unit and block was treated as a fixed effect. Orthogonal contrasts were constructed to determine the response curve (linear, quadratic, and cubic) of EO dose in the diet. Occurrences of liver abscesses were analyzed using the same procedure as Exp. 1.

Exp. 3

British x Continental crossbred yearling steers (n = 288; initial BW = 449; SD = 23 kg) were utilized in a randomized block design experiment at the UNL PREC in the fall of 2013. Upon arrival to the feedlot, steers were vaccinated with Express 5, treated with Ivomec, and given a visual identification tag. Prior to study initiation, steers were limit fed a 40% corn silage, 30% WDGS, and 30% wheat straw (DM basis) diet at 2% BW for 5 d to minimize variation in gut fill. Steer weighing, feeding, and sample collection procedures were the same as previously described in Exp. 1. Pens were assigned randomly to one of four treatments with 9 replications per treatment and 8 steers per pen. Light (420 kg), medium (449 kg), and heavy (478 kg) blocks consisted of 3, 4, and 2 replications, respectively.

A common basal diet was used for all four treatments (Table 3.1) consisting of 54% DRC, 25% WDGS, 15% corn silage, and 6% liquid supplement (DM basis). Treatments consisted of feeding EO at concentrations of 0, 16.5, 33.1, and 49.6 mg/kg of diet DM provided via micro-machine. Monensin and tylosin were provided in all treatments via micro-machine at 360 and 90 mg/steer daily, respectively. Steers were adapted to the common finishing diet over a 21 d period using 4 adaptation diets. The amount of WDGS and supplement included in each adaptation diet was held constant at 25 and 6% (DM basis), respectively. The amount of corn was gradually introduced in the diet while replacing the amount of wheat straw and corn silage. The first adaptation diet consisted of 30% corn silage, 20% wheat straw, and 19% DRC (DM basis) and was fed for 3 d. The second adaptation diet was fed for 4 d and consisted of 25% corn silage, 15% wheat straw, and 29% DRC (DM basis). The third adaptation step was fed for 7 d and consisted of 20% corn silage, 10% wheat straw, and 39% DRC (DM basis). The fourth and final adaptation diet was fed for 7 d and consisted of 15% corn silage, 5% wheat straw, and 49% DRC (DM basis). The nutrient composition for DRC used in this study was 88.0% DM, 8.0% NDF, 7.9% CP, 2.8% crude fat, < 0.01% Ca, 0.25% P, 0.26% K, 0.09% S, and 76.1% starch (DM basis). The WDGS used was 30.0% DM, 28.2% NDF, 31.6% CP, 7.8% crude fat, 0.05% Ca, 0.83% P, 1.07% K, 0.58% S, and 2.7% starch (DM basis). On a DM basis, the corn silage used was: 35.0% DM, 44.1% NDF 8.1% CP, 2.2% crude fat, 0.91% Ca, 0.27% P, 1.78% K, 0.15% S, and 21.7% starch.

Steers were implanted on day 0 with Revalor-XS. Steers in the medium and heavy blocks were fed for 98 days, while steers in the light block were fed for 118 days.

On day of shipping, cattle were weighed and transported to a commercial abattoir (Cargill Meat Solutions, Fort Morgan, CO.) and harvested. Final weighing conditions, carcass measurements, and animal performance used the same procedures as described in Exp. 1.

Performance and carcass characteristics were analyzed using the MIXED procedure of SAS (SAS Inst., Inc., Cary, N.C). Pen was the experimental unit and block was treated as a fixed effect. Orthogonal contrasts were constructed to determine the response curve (linear, quadratic, and cubic) for EO concentration in the diet. Occurrences of liver abscesses were analyzed the same as described in Exp. 1.

Results and Discussion

Exp. 1 Steer Performance and Carcass Characteristics

The interaction of MT x EO was not significant ($P \geq 0.46$; Table 3.2) for steer performance. There was no MT x EO interaction ($P = 0.10$; Table 3.2) for any carcass characteristics evaluated.

Main Effect of MT. Feeding MT had no effect on DMI ($P = 0.16$). Feeding monensin plus tylosin has previously been shown to reduce DMI (Potter et al., 1985; Stock et al., 1995; Meyer et al., 2009) or have no effect on DMI (Depenbusch et al., 2008; Meyer et al., 2013). Similarly, Meyer et al. (2009) observed a 5.8% decrease in DMI when steers were fed MT over a 115 d finishing period whereas Stock et al. (1995) observed a 1% reduction in DMI. In the current study, steers fed MT tended ($P = 0.07$) to have greater ADG, with steers fed MT gaining 2.8% faster than steers not fed MT. Similarly, Stock et al. (1995) and Meyer et al. (2013) both observed a similar response in ADG when monensin plus tylosin were fed. In contrast, Galyean et al. (1992) evaluated

monensin plus tylosin fed to steers consuming a high-concentrate diet and did not observe an improvement in ADG compared to steers not fed monensin plus tylosin. In the current study, the addition of MT improved ($P < 0.01$) G:F by 3.9% compared to steers without MT. These results are in close agreement with Meyer et al. (2013) who reported a 4.1% improvement in G:F when steers were fed monensin plus tylosin in diets containing WDGS. Furthermore, a 10.5% improvement in G:F was observed by Potter et al. (1985) summarizing data from 14 experiments comparing the effects of monensin plus tylosin when fed in combination compared to steers fed no monensin plus tylosin. Alternatively, Depenbusch et al. (2008) did not observe an improvement in G:F when monensin plus tylosin was fed in a diet consisting of steam-flaked corn (SFC) or a SFC diet with WDGS. The 3.9% improvement in G:F in the current study resulted primarily from small improvements in ADG for steers fed MT. To a lesser extent, the small (1.5%; $P = 0.16$) reduction in DMI when MT was fed may have also contributed to improved G:F. A tendency ($P = 0.07$) for an increase in carcass-adjusted final BW was observed for steers fed MT. Live final BW was greater ($P < 0.01$) for steers fed MT compared to steers without MT. There was a tendency ($P = 0.07$) for an increase in HCW and an improvement ($P < 0.01$) in marbling score for steers fed MT compared to steers without MT. Previous research has demonstrated unchanged (Heinemann et al., 1978) or decreased (Meyer et al., 2009) marbling score with the addition of monensin plus tylosin in finishing diets. In the current study, dressing percent, LM area, 12th rib fat thickness, and calculated yield grade were unaffected ($P \geq 0.19$) in the presence or absence of MT. The prevalence of liver abscesses ranged from 13.1 to 29.2% across treatments, which is similar to the observation of Brink et al. (1990). In the current study, the addition of MT

reduced ($P < 0.01$) total liver abscesses by 44.7% when compared to steers not receiving MT. The presence of liver abscesses (A) tended ($P = 0.08$) to decrease from 11.5 to 6.6% when steers were fed MT compared to steers not receiving MT. The incidence of severe (A+) liver abscesses was significantly ($P = 0.03$) less for steers fed MT (8.1%) compared to those receiving no MT (15.1%). A similar reduction in liver abscesses was observed with the use of monensin plus tylosin (Meyer et al., 2009; Meyer et al., 2013). However, Depenbusch et al. (2008) reported no differences in the occurrences of liver abscesses when comparing diets fed monensin plus tylosin to those fed no ionophores. Furthermore, Potter et al. (1985) suggested monensin alone does not impact liver abscesses. The reduction of liver abscesses, with the use of tylosin has been well documented (Pendlum et al., 1978; Potter et al., 1985; Vogel and Laudert, 1994; Meyer et al., 2013). However, due to the experimental design of the current experiment, differentiation as to what was a monensin effect or a tylosin effect on liver abscesses can't be concluded because monensin and tylosin were not provided independently of each other.

Main Effect of EO. There were no differences ($P = 0.58$; Table 3.2) in DMI between steers fed EO and those without EO. Yang et al. (2010b) supplemented increasing doses (0, 400, 800, or 1600 mg/hd/d) of cinnamaldehyde (CIN) to steers fed an 86% dry-rolled corn diet and observed a tendency for a quadratic effect on DMI, with DMI being least with the addition of CIN at 1600 mg/hd/d and greatest at 400 mg/hd/d. In the current study, ADG was not different ($P = 0.85$) for steers fed EO compared to steers fed diets without EO, which is similar to previous work with essential oils (Meyer et al., 2009; Yang et al., 2010b). In the current study, the addition of EO had no effect (P

= 0.87) on G:F. Meyer et al. (2009) reported a tendency for a 4.1% improvement in G:F with the addition of essential oils compared to steers fed no feed additives. Similarly, Benchaar et al. (2006) evaluated the effects of a commercial mixture of essential oils (Vertan; IDENA, Sautron, France) to steers fed a 75% grass/legume silage diet and observed a 5.5% improvement in feed efficiency with the addition of an essential oil mixture at 2 g/d compared to steers fed diets without essential oil. The commercial mixture of essential oils consisted mainly of thymol, eugenol, vanillin, and limonene. In the current experiment, no differences ($P \geq 0.80$) in carcass-adjusted BW and live final BW were observed due to feeding EO.

In the current study, the main effect of EO had no impact ($P \geq 0.75$) on HCW, dressing percent, marbling score, LM area, 12th rib fat thickness, or calculated yield grade. In agreement, Meyer et al. (2009) observed no differences in these carcass characteristics. Yang et al. (2010b) supplemented CIN at increasing doses to steers fed a high-concentrate diet and observed no differences in carcass characteristics. Furthermore, Chaves et al. (2008) supplemented lambs fed with either barley or corn grain based diets with CIN and garlic oil and observed no effect on carcass characteristics. In the current experiment, compared to steers fed no EO (18.9% liver abscesses), the addition of EO (22.6%) had no impact ($P = 0.37$) on the occurrence of total liver abscesses. Compared to steers fed no EO (6.7%), a tendency ($P = 0.10$) for the percentage of liver abscesses (A) increased when steers were fed EO (11.3%). The occurrence of severe liver abscesses (A+) was 11.3% for steers fed EO and 11.8% for steers that did not receive EO. Previous research evaluating the effects of essential oils on liver abscesses is minimal. Meyer et al. (2009) reported no difference in the

prevalence of liver abscesses with an experimental essential oil mixture containing guaiacol, linalool, and α -pinene, but observed a 39% decrease in liver abscesses using an essential oil mixture of thymol, eugenol, vanillin, guaiacol, and limonene compared to steers fed no additives.

Exp. 2

As dose of EO in the diet increased, DMI decreased linearly ($P = 0.04$; Table 3.3). Steers fed EO at 225 and 300 mg/steer daily resulted in a 4.2 and 2.9% reduction in DMI compared to steers fed 0 mg/steer daily EO. These results are in contrast to Yang et al. (2010b). Yang et al. (2010b) fed increasing doses of CIN to finishing steers and they observed a quadratic increase in feed intake with increasing doses of CIN. Intakes of steers fed 400 mg/hd/d of CIN were greatest (8.42 kg/d) while feeding 1800 mg/hd/d of CIN resulted in lowest intakes (7.69 kg/d), which is further supported by Yang et al. (2010a). Alternatively, Meyer et al. (2009) observed no differences in DMI when steers were fed essential oils compared to cattle fed without, which agrees with Exp. 1. In the current study, feeding increasing doses of EO had no effect on ADG ($P = 0.77$; linear). Results from Exp. 2 agree with Exp. 1 and are further supported by previous research (Meyer et al., 2009; Yang et al., 2010b) suggesting that essential oils have no effect on ADG. Gain efficiency increased linearly ($P = 0.02$) as dose of EO in the diet increased. Compared to 0 mg/steer daily EO, feeding EO at 225 and 300 mg/steer daily resulted in 4.4 and 3.8% improvement in G:F, respectively. Feeding 75 mg/steer daily of EO resulted in a 2.5% improvement in G:F compared with steers fed 0 mg/steer daily of EO. Similar to our findings in Exp. 2, Meyer et al. (2009) observed a 4.1% improvement in feed efficiency with the use of essential oils compared with control cattle. These findings

are in contrast to Yang et al. (2010b) who observed no differences in G:F when feeding increasing doses of CIN, which agrees with results from Exp. 1. In the current study, feeding increasing doses of EO had no effect of carcass adjusted final BW ($P = 0.75$; linear) or live final BW ($P = 0.44$; linear). Hot carcass weight, dressing percent, marbling score, and LM area were not different ($P \geq 0.19$; linear or quadratic) among treatments. However, calculated yield grade tended to decrease linearly ($P = 0.11$) as dose of EO increased. As dose of EO increased, 12th rib fat thickness decreased linearly ($P = 0.02$). The occurrence of liver abscesses tended to increase linearly ($P = 0.11$) with increasing doses of EO. The incidence of total liver abscesses ranged from 5.5% for steers fed 0 mg/steer daily EO to 11.4% for steers fed 300 mg/steer daily EO, which disagrees with the results from Exp. 1 when 300 mg/steer daily EO were provided.

Exp. 3

Increasing EO concentration in the diet did not affect DMI ($P > 0.59$; linear or quadratic; Table 3.4) with intakes of 14.2, 14.2, 14.1, and 14.3 kg for 0, 16.5, 33.1, and 49.6 mg/kg EO, respectively. Using the observed intakes, the calculated dose of EO provided was 0, 236, 467, and 709 mg/steer daily for treatments 0, 16.5, 33.1, and 49.6 mg/kg EO, respectively. For comparison to Exp. 2, EO dose were 0, 75, 150, 225, and 300 mg/steer daily. Steers fed EO at 225 and 300 mg/steer daily resulted in a 4.2% and 2.9% reduction in DMI compared to cattle fed 0 mg/steer daily EO. Results from Exp. 3 are contrary to Exp. 2, but are in agreement with Exp. 1 and previous research conducted by Meyer et al. (2009). It is unclear why DMI changes due to EO varied among experiments, but differences might be due to multiple factors (e.g., age of steer, DMI, finishing diet, or management). Potential management factors could be bunk

management, pen conditions, or type of diet fed. As concentration of EO increased, no differences ($P \geq 0.72$; linear or quadratic) in ADG or G:F were observed. These findings are similar to Exp. 1 and previous studies with essential oils having no effect on feed efficiency in beef steers (Meyer et al., 2009; Yang et al., 2010b) and lambs (Chaves et al., 2011). Feeding increasing concentrations of EO had no effect ($P \geq 0.64$; linear or quadratic) on carcass-adjusted final BW or live final BW. Hot carcass weight, 12th rib fat depth, dressing percent, and calculated yield grade were not affected ($P \geq 0.22$; linear or quadratic) by EO concentration. A tendency ($P = 0.06$) for a linear increase in marbling score was observed as concentration of EO increased, which is contrary to Exp. 2 and previous research evaluating the effects of essential oils in finishing diets (Meyer et al., 2009; Yang et al., 2010b). As EO concentration increased, a tendency ($P = 0.06$) for LM area to decrease quadratically was observed. Yearling steers fed 0 or 49.6 mg/kg EO had the greatest LM area, while feeding 33.1 mg/kg EO produced the smallest LM area. The occurrence of liver abscesses increased quadratically ($P = 0.05$) as the concentration of EO increased in the diet. Occurrence of liver abscesses increased by 8.3 and 2.8% when feeding 33.1 and 49.6 mg/kg EO (respectively) compared to steers fed 0 mg/kg EO. Similarly, feeding increasing doses of EO in Exp. 2 resulted in an increase in occurrence of liver abscesses. However, reduced responses in G:F was not observed in Exp. 2 or 3 with the increase in occurrence of liver abscesses.

The findings of these experiments and previously published research utilizing essential oils in feedlot finishing diets have been quite variable. Including EO in finishing diets has led to inconsistent results in animal performance over the entire finishing period. Feed efficiency was improved when cattle were fed monensin plus

tylosin. Additionally, the prevalence of liver abscesses decreased with the inclusion of monensin plus tylosin in the diet. However, previous research and the current data suggest that essential oils have little effect on growth performance and carcass characteristics.

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1

2

Table 3.1. Dry matter composition of dietary treatments used for Exp. 1, 2, and 3

Ingredient, %	Exp. 1	Exp. 2	Exp. 3
Dry-rolled corn	53.0	65.0	54.0
Wet distillers grains plus solubles	25.0	25.0	25.0
Corn Silage	16.0	-	15.0
Wheat Straw	-	5.0	-
Supplement ¹	6.0	5.0	6.0
<i>Analyzed Composition, %</i>			
Crude Protein	13.9	13.6	13.4
Calcium	0.52	0.41	0.61
Phosphorus	0.40	0.39	0.39
Potassium	0.92	0.78	0.95
Ether Extract	4.84	4.97	3.84
Neutral Detergent Fiber	22.3	20.3	18.0
Starch	42.4	46.4	45.0
Sulfur	0.16	0.19	0.22

¹Supplement was formulated to provide a dietary DM inclusion of 0.3% salt, 60 mg/kg Fe, 40 mg/kg Mg, 25 mg/kg Mn, 10 mg/kg Cu, 1 mg/kg I, 0.15 mg/kg Se, 1.5 IU/g vitamin A, 0.15 IU of vitamin D, and 8.81 IU/kg vitamin E.

Table 3.2. Effect of essential oils and monensin/tylosin on calf-fed steer performance and carcass characteristics in Exp. 1

Item	Treatment ¹				SEM	<i>P-value</i>		
	CON	EO	MT	EOMT		EO ²	MT ³	EO x MT ⁴
<i>Performance</i>								
Initial BW, kg	295	295	295	295	0.49	0.44	0.80	0.70
DMI, kg /d	10.1	10.2	10.0	10.0	0.1	0.58	0.16	0.46
ADG, kg ⁵	1.78	1.79	1.83	1.82	0.03	0.85	0.07	0.61
G:F	0.176	0.176	0.183	0.183	0.003	0.87	<0.01	0.96
Final BW, kg ⁵	556	559	565	564	3.7	0.81	0.07	0.59
Final Live BW, kg	583	584	593	593	3.1	0.80	<0.01	0.89
<i>Carcass Characteristics</i>								
HCW, kg	351	352	356	355	2.3	0.80	0.07	0.59
Dressing, %	62.7	62.8	62.6	62.4	0.3	0.98	0.27	0.53
Marbling ⁶	523	531	558	555	8	0.76	<0.01	0.48
LM area, cm ²	78.8	78.1	77.4	78.5	0.6	0.75	0.46	0.14
12 th rib fat, cm	1.48	1.52	1.55	1.50	0.03	0.90	0.55	0.17
Calculated YG ⁷	3.39	3.48	3.56	3.46	0.06	0.92	0.19	0.10
Liver abscess ⁸ , %	24.7	29.2	13.1	16.2	-	0.37	<0.01	0.97
A, %	9.4	13.5	4.0	9.1	-	0.10	0.08	0.56
A+, %	14.6	15.6	9.1	7.1	-	0.77	0.03	0.59

¹CON = Control, EO = essential oil (Novus International, Inc., St. Charles, MO) provided at 300 mg/steer daily, MT = monensin (Elanco Animal Health, Greenfield, IN) provided at 360 mg/steer daily +tylosin (Elanco Animal Health) provided at 90 mg/steer daily , EOMT = essential oil provided at 300 mg/steer daily + monensin provided at 360 mg/steer daily +tylosin provided at 90 mg/steer daily.

²EO = *P*-value for the main effect of essential oil inclusion.

³MT = *P*-value for the main effect of monensin/tylosin inclusion.

⁴EO x MT = *P*-value for the essential oil x monensin/tylosin interaction.

⁵Calculated from carcass weight, adjusted to 63% common dressing percent.

⁶Marbling Score: 400 = slight, 500 = small, 600 = modest, etc.

⁷Calculated YG = 2.50 + (6.35*fat thickness, cm) + (0.2*KPH,%) + (0.0017*HCW, kg) – (2.06*LM area, cm²).

⁸Liver score: A = 1 or 2 small abscesses, up to 2 to 4 well organized abscesses; A+ = 1 or more large, active abscesses.

Table 3.3. Effect of essential oil dose in finishing diets on calf-fed steer performance and carcass characteristics in Exp. 2

Item	Essential oil ¹ , mg per steer daily					SEM	<i>P-value</i>	
	0	75	150	225	300		Lin. ²	Quad. ³
<i>Performance</i>								
Initial BW, kg	297	298	297	297	298	0.5	1.00	0.55
DMI, kg/day	10.8	10.6	10.6	10.3	10.5	0.1	0.04	0.38
ADG, kg ⁴	1.71	1.73	1.73	1.71	1.73	0.02	0.77	0.90
G:F	0.159	0.163	0.164	0.166	0.165	0.002	0.02	0.34
Final BW, kg ⁴	573	576	575	572	577	4	0.75	0.94
Final Live BW, kg	597	598	600	595	603	4	0.44	0.62
<i>Carcass Characteristics</i>								
HCW, kg	361	363	362	361	363	2	0.76	0.96
Dressing,%	63.0	63.3	62.9	63.1	62.7	0.2	0.31	0.32
Marbling ⁵	455	461	457	443	480	10	0.34	0.19
LM area, cm ²	77.9	77.7	78.0	79.7	77.9	0.8	0.42	0.50
12 th rib fat, cm	1.45	1.50	1.45	1.40	1.40	0.03	0.02	0.32
Calculated YG ⁶	3.57	3.69	3.60	3.44	3.55	0.06	0.11	0.75
Liver abscess ⁷ , %	5.5	5.9	11.3	11.3	11.4	-	0.11	0.62
A, %	2.8	4.4	7.0	11.3	7.1	-	0.11	0.35
A+, %	2.8	1.5	4.2	0.0	4.3	-	-	-

¹Essential oil (Novus International, Inc., St. Charles, MO).

²Lin. = *P*-value for the linear response to essential oil.

³Quad. = *P*-value for the quadratic response to essential oil.

⁴Calculated from carcass weight, adjusted to 63% common dressing percent.

⁵Marbling Score: 400 = slight, 500 = small, 600 = modest, etc.

⁶Calculated YG = 2.50 + (6.35*fat thickness, cm) + (0.2*KPH, %) + (0.0017*HCW, kg) – (2.06*LM area, cm²).

⁷Liver score: A = 1 or 2 small abscesses, up to 2 to 4 well organized abscesses; A+ = 1 or more large, active abscesses.

Table 3.4. Effects of essential oil concentration in finishing diets on yearling steer performance and carcass characteristics in Exp. 3

	Essential oil ¹ , mg/kg (mg per steer daily)					<i>P-value</i>	
Item	0	16.5(234)	33.1(467)	49.6(709)	SEM	Lin. ²	Quad. ³
<i>Performance</i>							
Initial BW, kg	449	449	449	449	0.5	0.53	0.64
DMI, kg/day	14.2	14.2	14.1	14.3	0.1	0.96	0.60
ADG, kg ⁴	1.96	1.98	1.95	1.97	0.03	0.99	0.98
G:F	0.138	0.139	0.138	0.138	0.001	0.96	0.72
Final BW, kg ⁴	653	656	653	656	4	0.76	0.99
Final Live BW, kg	682	689	681	687	3	0.64	0.98
<i>Carcass Characteristics</i>							
HCW, kg	411	413	411	413	2	0.76	1.00
Dressing, %	60.3	60.0	60.5	60.1	0.2	0.83	0.95
Marbling ⁵	484	494	490	510	9	0.06	0.60
LM area, cm ²	81.9	80.6	79.4	81.3	0.6	0.57	0.06
12 th rib fat, cm	1.30	1.35	1.32	1.35	0.03	0.31	0.76
Calculated YG ⁶	3.7	3.8	3.8	3.7	0.06	0.31	0.22
Liver Abscess ⁷ , %	1.4	6.9	9.7	4.2	-	0.29	0.05
A, %	1.4	5.6	8.3	4.2	-	0.23	0.11
A+, %	0.0	1.4	1.4	0.0	-	-	-

¹Essential oil (Novus International, Inc., St. Charles, MO).

²Lin. = *P*-value for the linear response to essential oil concentration.

³Quad. = *P*-value for the quadratic response to essential oil concentration.

⁴Calculated from carcass weight, adjusted to 63% common dressing percent.

⁵Marbling Score: 400 = Small, 500 = Modest, etc.

⁶Calculated YG = 2.50 + (6.35*fat thickness, cm) + (0.2*KPH, %) + (0.0017*HCW, kg) – (2.06*LM area, cm²).

⁷Liver score: A = 1 or 2 small abscesses, up to 2 to 4 well organized abscesses; A+ = 1 or more large, active abscesses.

**CHAPTER IV. EVALUATION OF RACTOPAMINE HYDROCHLORIDE
(OPTAFLEXX) ON GROWTH PERFORMAMANCE AND CARCASS
CHARACTERISTICS OF FINISHING STEERS ACROSS DIFFERENT
FEEDING DURATIONS**

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ABSTRACT

Two experiments were conducted to evaluate the effects of ractopamine hydrochloride (RAC) dose and duration on growth performance and carcass characteristics of finishing steers. In Exp. 1, 336 crossbred steers (initial BW of RAC feeding = 539 kg; SD = 22 kg) were utilized in a 2×2 factorial arrangement of treatments with one factor being RAC dose (0 or 200 mg/steer daily) and the other factor being RAC duration (28 or 42 d prior to harvest). There were no RAC dose \times duration interactions ($P \geq 0.08$) for growth performance or carcass characteristics. Feeding 200 mg of RAC/steer daily increased ($P < 0.01$) live final BW by 9.0 kg compared to steers not fed RAC. Carcass-adjusted final BW, ADG, and G:F were greater ($P < 0.01$) for steers fed 200 mg of RAC/d compared to steers not fed RAC. Hot carcass weight was 4.7 kg heavier ($P < 0.01$) for steers fed 200 mg of RAC/d compared to steers not fed RAC. In Exp. 2, crossbred steers ($n = 576$; experiment initial BW = 408 kg; SD = 29 kg) were utilized in a randomized block design with a 3×3 factorial arrangement of treatments. Factors included RAC dose (0, 300, and 400 mg/steer daily) and RAC duration (14, 28, or 42 d prior to harvest). There was a tendency ($P \leq 0.08$) for an interaction of RAC dose \times duration for final live BW, DMI, and live G:F, therefore simple effects are presented. At 28 d, live final BW for steers fed 400 mg RAC were heavier ($P < 0.01$) than steers fed 0 mg RAC. There was a tendency at 28 d for increased live final BW for steers fed RAC at 300 mg ($P = 0.08$) compared to 0 mg and for steers fed 400 mg of RAC compared to 300 mg ($P = 0.06$). Live final BW was greater ($P < 0.01$) for steers fed RAC for 42 d at 300 and 400 mg compared to steers fed 0 mg; however, live final BW was similar ($P = 0.48$) between 300 and 400 mg of RAC.

Despite no RAC dose \times duration interaction ($P = 0.30$) for HCW, simple effects will be presented for consistency. Hot carcass weight was greater for steers fed 300 and 400 mg of RAC for 28 and 42 d compared to steers fed 0 mg at 28 d ($P \leq 0.02$) and 42 d ($P < 0.01$). Feeding 300 mg of RAC for 28 or 42 d increased HCW by 5.1 and 7.6 kg compared to steers fed 0 mg of RAC. Additionally, feeding 400 mg of RAC for 28 or 42 d resulted in increases of 8.9 and 9.4 kg in HCW compared to steers fed 0 mg of RAC. In conclusion, our results confirm that feeding RAC improves growth performance and carcass weight, with an optimal duration of feeding RAC being 28 d.

Key Words: dose, duration, feedlot, ractopamine hydrochloride

INTRODUCTION

Ractopamine hydrochloride (**RAC**; Optaflexx; Elanco Animal Health, Greenfield, IN) is a beta-adrenergic agonist (**β -AA**) and is approved for feeding during the last 28 to 42 days of the finishing period at a rate of 10.0 to 30.0 mg RAC/kg (DM basis) and to provide 70 to 430 mg RAC/steer daily with no withdrawal period (FDA, 2003). Beta-adrenergic agonists have been shown to increase protein accretion and decrease fat accretion in animal growth by increasing protein synthesis and decreasing protein degradation (Mersmann, 1998). When fed at a rate of 100 to 300 mg RAC/steer daily, RAC improves feed efficiency, live final BW, and HCW when fed to steers the last 28 to 42 days of the finishing period (Boler et al., 2012; Pyatt et al., 2013; Bohrer et al., 2014; Bittner et al., 2016).

Market shifts and environmental factors make optimal slaughter dates challenging to predict prior to the start of feeding RAC. The ability to accurately predict performance

during the latter part of the finishing phase is critically important to feedlot managers faced with decisions that may affect animal growth and carcass characteristics. Accurately predicting ADG and G:F late in the feeding period is especially challenging as performance typically declines with increased days on feed (Van Koeveering et al., 1995; Winterholler et al., 2007). However, this reduction in growth performance can be at least partially offset by feeding RAC prior to harvest. Currently, there are limited data evaluating the effects of feeding RAC over time, or the effects of RAC when cattle are fed past their projected slaughter date. Furthermore, no data exist evaluating the effects of feeding RAC to steers for less than 28 days due to Food and Drug Administration (FDA) restrictions. Feeding RAC for 28 to 42 d prior to harvest should improve ADG and feed efficiency late in the feeding period. Therefore, the objectives of these experiments were to evaluate the effects of RAC dose and duration of RAC feeding on growth performance and carcass characteristics of finishing steers.

MATERIALS AND METHODS

All facilities and procedures were approved by the University of Nebraska Institutional Animal Care and Use Committee and by the FDA (Investigational New Animal Drug number 4736).

Exp. 1

Three hundred thirty-six British × Continental crossbred steers (initial BW = 539 kg; SD = 22 kg) were utilized in a randomized block design experiment. Steers were received at the University of Nebraska's Agricultural Research and Development Center (ARDC; near Mead, NE) in the fall of 2004. Upon arrival at the feedlot, steers were

processed and vaccinated with Titanium 5 (Elanco Animal Health), Haemophilus Somnus Bacterin (Zoetis, Inc., Kalamazoo, MI), Once PMH (Merck Animal Health, De Soto, KS), treated for internal and external parasites (Cydectin, Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), and given an electronic and visual identification tag. Approximately 2 weeks later, all steers were re-vaccinated with Pyramid 5 (Boehringer Ingelheim Vetmedica, Inc.) and vaccinated with Vision 7 (Merck Animal Health). On d 1, steers were given an initial implant Synovex Choice (14 mg estradiol benzoate, 100 mg trenbolone acetate; Zoetis, Inc.) and were managed for a pre-trial phase (83 d) in pens of 20 steers/pen. On d 83 in the spring, all steers were re-implanted with Synovex Choice (Zoetis, Inc.). Steers were individually weighed (Silencer Squeeze Chute; Moly Mfg. Inc., Lorraine, KS: scale readability ± 0.45 kg) on d 83 and 84 to establish initial BW (Stock et al., 1983), blocked by 83 d BW, stratified within blocks (light = 418 kg, medium = 449 kg, heavy = 486 kg), and assigned randomly to 28 pens. Pens were assigned randomly to one of four treatments with 7 replications per treatment and 12 steers per pen. Light, medium, and heavy blocks consisted of 1, 5, and 1 replications, respectively. On d 137, all steers were pen weighed (shrunk 4%), and this BW was used as initial BW of RAC feeding, and RAC treatments were initiated.

A 2×2 factorial arrangement of treatments was used with one factor being RAC dose (0 (**0 mg of RAC**) or 200 mg RAC/steer daily (**200 mg of RAC**)) and the other factor being RAC duration (28 or 42 d prior to harvest). A common basal diet was fed to all four treatments consisting of 58.5% high-moisture corn (**HMC**), 30% Sweet Bran (Cargill Corn Milling, Blair, NE), 7.5% alfalfa hay, and 4% supplement (DM basis; Table 1). Steers were adapted to the common finishing diet by feeding four adaptation diets.

Alfalfa hay inclusion was gradually decreased from 45 to 7.5% (DM basis), while inclusion of HMC increased from 21 to 58.5% (DM basis) during the adaptation period. Sweet Bran and supplement were included in all adaptation diets at 30 and 4% (DM basis), respectively. The supplement was formulated for 29.2 mg monensin/kg DM (Rumensin; Elanco Animal Health) and to provide 90 mg tylosin/steer daily (Tylan; Elanco Animal Health).

Steers were housed in open feedlot pens with 76.2 to 81.3 cm of linear bunk space and 47.0 to 59.3 m² of pen space per steer. Feed bunks were assessed daily at approximately 0600 for presence of feed. Feed amounts were increased or decreased daily to maintain a clean bunk system at time of feeding. Cattle were fed twice daily (0730 and 1230 h). Steers had ad libitum access to fresh clean water and their respective diet. Diets were mixed and delivered daily using a truck-mounted feed mixer and delivery unit (Roto-Mix model 420, Roto-Mix, Dodge City, KS). Ractopamine hydrochloride treatments were applied daily in a meal supplement fed at 4% of the diet DM. Two feed samples were collected from each batch of feed during the first and last weeks of the study. Feed samples were sent to SDK Laboratories (Hutchinson, KS) for chemical analysis. Upon arrival at SDK Laboratories, samples were composited and separated into four equal aliquots. Two aliquots were then sent to Eurofins Scientific (Memphis, TN) for analysis of RAC and monensin concentrations. The expected concentration of monensin was 18.8 mg/kg of monensin (as-is) and the assay reported 21.2 mg/kg monensin (as-is). Acceptable tolerances (i.e., pass) are 85 to 115% of the claim for monensin. Expected concentration of RAC was 13.8 mg/kg RAC (as-is) and the

analysis reported 11.0 mg/kg RAC (as-is). Acceptable tolerances are 80 to 110% of the claim for RAC.

Ractopamine hydrochloride was initiated to all steers on the same d. Therefore, steers fed RAC for 42 d were on feed for an additional 14 d compared with the 28 d RAC fed steers. Two weeks prior to treatment initiation and every 7 d thereafter, steers were removed from their pens (prior to feeding) and pen weights were collected using a pen scale. Pen weights (4% pencil shrink applied) were collected every 7 d to evaluate animal performance over the RAC treatment phase. All residual feed remaining at the time the steers were removed from their pen was weighed.

On d of shipping, steers were fed in the morning and pen weighed in the afternoon to determine live final BW before being loaded on the truck. Live final BW were pencil shrunk 4% to calculate live animal performance and dressing percent. Steers on the 28 d duration treatments were on feed for 165 d, while steers on the 42 d duration treatments were on feed for an additional 14 d (179 d). Steers were harvested, using captive-bolt stunning, at a commercial abattoir (Excel Corp., Schuyler, NE). On d of harvest, HCW and liver scores were recorded. After a 36 h chill, LM area, fat thickness, and USDA marbling score were recorded. Yield grade was calculated (USDA, 1997) from the following formula: $2.50 + (6.35 * \text{fat thickness, cm}) + (0.2 * 2.5 [\text{KPH}]) + (0.0017 * \text{HCW, kg}) - (2.06 * \text{LM area, cm}^2)$. With the use of a common dressing percent (63%), carcass adjusted final BW, ADG, and G:F were calculated. Steer growth performance was calculated during the RAC treatment phase (28 or 42 d).

Growth performance and carcass characteristics were analyzed as a 2×2 factorial using the MIXED procedure of SAS (Version 9.2; SAS Inst., Inc., Cary, NC) with pen being the experimental unit. The model included the effects of RAC dose, duration, block and RAC dose \times duration interaction. On the morning of RAC feeding, live BW were collected and used as a covariate in the model. If the covariate was not significant ($P \leq 0.05$) for the variable of interest, then the covariate was removed from the model. Covariate were included in the analysis of live final BW, carcass-adjusted final BW, and HCW. If no significant RAC dose \times duration interaction ($P \leq 0.10$) was observed, the main effects of RAC dose and duration were evaluated. Differences are discussed at $P \leq 0.05$ and tendencies discussed between $P > 0.05$ and $P \leq 0.10$.

Exp. 2

British \times Continental crossbred yearling steers ($n = 576$; initial BW = 408; SD = 29 kg) were used in a randomized block design ($n = 4$ BW blocks) with a 3×3 factorial treatment design to study the effects of RAC dose and duration of RAC feeding on growth performance and carcass characteristics. Steers were received at the ARDC near Mead, NE in the fall of 2012. Within 24 hours of arrival, steers were processed and vaccinated with Vista Once SQ (Merck Animal Health, De Soto, KS), injected with Cydectin (Boehringer Ingelheim Vetmedica, Inc., St. Joseph, MO), orally drenched with Safe-Guard (Merck Animal Health), and individually identified (panel tag, metal tag, and electronic ear button). Approximately 2 weeks later, steers were re-vaccinated with Vista 5 SC (Merck Animal Health), vaccinated with a Vision 7 (Merck Animal Health), Piliguard Pinkeye Triview (Merck Animal Health), and injected with 1.5 mL/45.4 kg of BW of Micotil (Elanco Animal Health) for control of bovine respiratory disease. Steers

were managed on corn residue and supplemented with 2.27 kg/d (DM basis) of Sweet Bran through the winter and spring seasons. Prior to the finishing study, 465 steers were utilized in an 87 d growing study, non-related to the current study, while the remaining 119 steers were managed in feedlot pens and fed a diet consisting of 60% Sweet Bran and 40% wheat straw (DM basis).

Prior to initiation of trial, steers were limit fed at 2% BW for 5 d a diet consisting of 50% Sweet Bran and 50% alfalfa hay (DM basis) to minimize variation in gastrointestinal fill (Watson et al., 2013). Steers were individually weighed (Silencer Squeeze Chute; scale readability ± 0.91 kg) on days 0 and 1 to establish initial BW and used as initial BW of the experiment. Steers were blocked by d 0 BW, stratified by BW, and assigned randomly within strata to pens. Pens were assigned randomly to treatments. The study consisted of 8 pens per treatment with 8 steers per pen.

A 3×3 factorial arrangement of treatments was used with one factor being RAC dose (0, 300, and 400 mg/steer daily) and the other factor being RAC duration (14, 28, or 42 d prior to harvest). Steers were adapted to a common finishing diet (Table 1) consisting of 28% HMC, 18% dry-rolled corn (**DRC**), 25% modified distillers grains plus solubles (**MDGS**; Archer Daniels Midland Company, Columbus, NE), 20% Sweet Bran, 5% wheat straw, and 4% dry meal supplement (DM basis) over a 19 d period consisting of four adaptation diets. The MDGS, Sweet Bran, wheat straw, and supplement included in each adaptation diet was held constant at 25, 20, 5, and 4% (DM basis), respectively. Alfalfa hay inclusion was gradually decreased from 35 to 5% (DM basis), while inclusion of DRC increased from 5.5 to 20% (DM basis) and HMC increased from 5.5 to 21% (DM

basis) simultaneously. The supplement was formulated for 33 mg monensin/kg DM and to provide 90 mg/steer daily of tylosin.

Steers were housed in open dirt feedlot pens, 61.5 to 92.5 m² of pen space, and 76.2 to 121.9 cm of linear bunk space per steer. Feed bunks were assessed daily at approximately 0600 h for presence of feed. Bunks were managed daily so that only trace (≤ 0.2 kg) amounts of feed were present in the bunk at time of feeding. Refused feed was removed as needed, weighed, sampled, and dried in a forced-air oven for 48 h at 60°C for DM determination (AOAC, 1999 method 4.10.3), to obtain accurate DMI. Cattle were fed once daily between 0700 and 0900. Steers had *ad libitum* access to fresh clean water and their respective diet. Diets were mixed and delivered daily using a truck-mounted feed mixer and delivery unit (Roto-Mix model 274, Roto-Mix, Dodge City, KS; scale readability ± 0.91 kg). Individual ingredient samples were taken weekly and analyzed for DM content. Weekly ingredient samples were composited by month for subsequent nutrient content determination. Ractopamine hydrochloride top-dress supplements were sampled during the manufacturing process ($n = 3$ per treatment) and submitted for ractopamine assay at a commercial laboratory (Covance Inc., Greenfield, IN). The expected concentration of RAC in the top dress for steers fed 300 mg RAC was 661 mg/kg RAC and the assay reported 651 mg/kg RAC. The expected concentration of RAC in the top dress for steers fed 400 mg RAC was 794 mg/kg RAC and the assay reported 818 mg/kg RAC. The acceptable tolerances for RAC were the same as reported in Exp. 1.

Ractopamine hydrochloride was initiated to steers on the same d, within blocks. Therefore, harvest dates were staggered (14 d apart) based on treatment group (duration of feeding). Two weeks prior to treatment initiation and every 7 d thereafter, steers were removed from their pens (approximately 0700) and pen weights were collected using a pen scale (Norac M2000; NORAC Inc., Bloomington, MN) prior to feeding on the scheduled weigh days. On the morning of treatment initiation, each pen was removed and weighed. This weight (shrunk 4%) was used as initial BW of RAC feeding. All residual feed remaining in the bunk was removed and weighed. Pen weights (4% pencil shrink applied) were collected every 7 d to evaluate steer growth performance over the RAC treatment phase. Ractopamine hydrochloride was delivered daily during the treatment phase via top-dress at either 300 or 400 mg RAC/steer daily, depending on treatment, with fine ground corn used as the carrier. Three top-dress supplements were used during the treatment phase, one that contained no RAC (0.45 kg/steer daily of fine ground corn), one that contained 300 mg of RAC (0.45 kg/steer daily of a 661 mg RAC/kg medicated supplement), and one that contained 400 mg of RAC (0.50 kg/steer daily of a 794 mg RAC/kg medicated supplement). A USDA approved food grade dye (Sensient Technologies Corp., St. Louis, MO) was added to the top-dress supplements (300 and 400 mg of RAC) during the manufacturing process as an aid to ensure that the appropriate top-dress was fed to the correct pen daily.

One hundred days prior to the target marketing date for steers on the 28 d treatment all steers were implanted with Component TE-S with Tylan (24 mg of estradiol, 120 mg trenbolone acetate, and 29 mg of tylosin tartrate; Elanco Animal Health). The terminal implant window ranged from 86 to 114 d, depending on treatment

duration. Steers in blocks 1 and 2 were on feed for an average of 125 d; total days on feed (**DOF**) was 111, 125, or 139 d by duration, respectively. Steers in blocks 3 and 4 were on feed for an average of 148 d; total DOF was 134, 148, or 162 d by duration, respectively. Steers were on RAC for 14, 28, or 42 d prior to harvest. On day of shipping, cattle were fed 50% of the previous days feed call and then in the afternoon all cattle to be shipped were removed from their pens, pen weighed to determine final live BW, and loaded onto the truck. Steers were harvested, using captive-bolt stunning, at Greater Omaha Packing Co., Inc. (Omaha, NE) the following morning. Hot carcass weight and liver scores were obtained on day of harvest. After a 48 h chill, USDA marbling score, 12th rib fat depth, and LM area were recorded. Yield grade was calculated as described in Exp. 1. With the use of a common dressing percentage (63%), carcass-adjusted final BW, ADG, and G:F were calculated. Final live BW were pencil shrunk 4% to calculate dressing percent and live animal performance. Steer growth performance was calculated over the entire feeding period.

Growth performance and carcass characteristics were analyzed as a 3×3 factorial using the MIXED procedure of SAS (Version 9.2; SAS Inst., Inc., Cary, NC) with pen being the experimental unit. The model included the effects of RAC dose, duration, and RAC dose \times duration interaction. Block was treated as a random effect. On the morning of RAC initiation, live BW were collected and used as a covariate in the model. If the covariate was not significant ($P \leq 0.05$) for the variable of interest, then the covariate was removed from model. No covariate were included in the analysis of LM area, dressing percent, fat thickness, marbling score, yield grade, and quality grade. Orthogonal polynomial contrasts were also constructed to determine the response curve (linear and

quadratic) for RAC dose when looking at final live BW and HCW change over RAC feeding duration using the MIXED procedure of SAS. Frequency data (yield and quality grade distributions) were analyzed using binomial proportions with the GLIMMIX procedure of SAS. The least square means and SE of the proportions for the frequency data were determined using the ILINK option. Treatment differences are discussed at $P \leq 0.05$ and tendencies discussed between $0.05 < P \leq 0.10$.

RESULTS

Exp. 1

The interaction of RAC dose \times duration was not significant for steer growth performance ($P \geq 0.40$) or carcass characteristics ($P \geq 0.11$). For the purpose of this article the main effects will be discussed; however, to appropriately distinguish the differences between feeding 200 mg of RAC for either 28 or 42 d, the simple effects (Tables 2 and 3) will be presented. Results for steer growth performance are only reported for the treatment phase of RAC (i.e., the last 28 or 42 d prior to slaughter). Live final BW was greater ($P < 0.01$) for steers fed 200 mg of RAC compared to steers fed 0 mg of RAC. Steers fed 200 mg of RAC were 9.0 kg heavier than steers fed 0 mg of RAC. Figure 1 shows the live BW performance profile response curves for steers fed 200 mg of RAC. Feeding 200 mg of RAC had a quadratic effect ($R^2 = 0.98$; $P < 0.01$; $y = -0.0048x^2 + 0.4038x$) on live BW as duration increased. Ractopamine dose had no effect ($P = 0.88$) on DMI. Live ADG and G:F increased ($P < 0.01$) when steers were fed 200 mg of RAC compared with steers fed 0 mg of RAC. Carcass-adjusted final BW, ADG, and G:F was greater ($P < 0.01$) for steers fed 200 mg of RAC compared to steers

fed 0 mg of RAC. Feeding 200 mg of RAC resulted in a 14.2% improvement in G:F compared with 0 mg of RAC fed steers. Hot carcass weight was 4.7 kg greater ($P < 0.01$) for 200 mg of RAC fed steers compared with 0 mg of RAC; however, dressing percent, marbling score, fat thickness, LM area, and calculated yield grade did not differ ($P \geq 0.35$) between RAC dose.

Live final BW was greater ($P < 0.01$) for steers fed 42 d compared with steers fed 28 d. Daily DMI was slightly greater (10.5 vs. 10.9 kg/d; $P < 0.01$) for steers fed for 42 d than 28 d. Live ADG tended ($P = 0.10$) to decrease when steers were fed for 42 d compared with 28 d. Feed efficiency was greater ($P < 0.01$) for steers fed for 28 d than 42 d fed steers. Carcass-adjusted final BW was greater ($P < 0.01$) for steers fed for 42 d compared with steers fed 28 d. Carcass-adjusted ADG was greater ($P = 0.08$) for steers fed for 42 d compared with 28 d. Feed efficiency was greater ($P < 0.01$) for steers fed for 28 d compared with 42 d. Feeding steers for 28 d resulted in a 9.2% improvement in G:F compared with steers fed for 42 d. Hot carcass weight was greater ($P < 0.01$) for steers fed for 42 d than 28 d. Dressing percent, fat thickness, and LM area was greater ($P \leq 0.04$) for steers fed 42 d compared with steers fed for 28 d. Feeding steers for 28 or 42 d had no effect ($P \geq 0.41$) on marbling score or calculated yield grade.

To make the comparison between feeding steers 200 mg of RAC for 28 or 42 d, the simple effects will be presented for live final BW and HCW. Steers fed 200 mg of RAC for 28 d increased ($P < 0.01$) live final BW 9.0 kg compared to steers fed 0 mg of RAC for 28 d. Similarly, feeding 200 mg of RAC for 42 d resulted in a 9.0 kg improvement ($P < 0.01$) in final live BW compared with steers fed 0 mg of RAC for 42

d. Hot carcass weight was 5.5 kg heavier ($P < 0.01$) for steers fed 200 mg of RAC for 28 d compared with steers fed 0 mg of RAC for 28 d. Feeding 200 mg of RAC for 42 d increased ($P = 0.02$) HCW 3.9 kg over steers fed 0 mg of RAC for 42 d.

Exp. 2

There was a tendency ($P \leq 0.08$) for a RAC dose \times duration interaction for final live BW, DMI, and live G:F (Table 4), therefore simple effects will be presented. Results for steer growth performance are reported over the entire feeding period. Live final BW was not different ($P \geq 0.40$) for steers fed 0, 300, or 400 mg RAC for 14 d. At 28 d, live final BW was 11.9 kg heavier ($P < 0.01$) for steers fed 400 mg of RAC than steers fed 0 mg RAC. Steers fed 300 mg RAC tended ($P = 0.08$) to be 5.8 kg heavier than steers fed 0 mg at 28 d. Feeding 400 mg RAC for 28 d tended ($P = 0.06$) to increase live final BW 6.3 kg compared with steers fed 300 mg RAC. Live final BW was 13.4 and 11.1 kg greater ($P < 0.01$) for steers fed RAC for 42 d at 300 and 400 mg, respectively, compared to 0 mg fed steers. Live final BW was not different ($P = 0.48$) between steers fed RAC at 300 and 400 mg for 42 d. Figure 1 shows the live BW performance profile response curves for feeding steers 300 and 400 mg of RAC. A quadratic effect of feeding 300 ($R^2 = 0.91$; $P < 0.01$; ($y = -0.0049x^2 + 0.5157x$)) and 400 ($R^2 = 0.99$; $P < 0.01$; ($y = -0.0081x^2 + 0.5956x$)) mg of RAC was observed for weekly live BW response.

Dry matter intake was not different ($P \geq 0.16$) between steers fed 0, 300, and 400 mg of RAC for 14 and 42 d. Within 28 d, DMI was 0.4 kg/d greater ($P \leq 0.03$) for steers fed 0 mg RAC compared with 300 and 400 mg RAC fed steers. Carcass-adjusted final BW was not different ($P > 0.12$) between steers fed 0, 300, and 400 mg of RAC for 14 d.

At 28 d, feeding 300 and 400 mg of RAC increased ($P < 0.05$) carcass-adjusted final BW compared with steers fed 0 mg of RAC. Similarly, carcass-adjusted final BW was greater ($P < 0.01$) for steers fed 300 and 400 mg of RAC for 42 d compared with 0 mg RAC fed steers for 42 d. Carcass-adjusted ADG was not different ($P = 0.26$; 1.66 vs 1.69 kg) between steers fed RAC at 0 and 300 mg for 14 d. Carcass-adjusted ADG tended ($P = 0.06$) to be greater for steers fed RAC at 400 mg (1.71 kg) compared to 0 mg (1.66 kg) of RAC for 14 d; however, carcass-adjusted ADG was not different ($P = 0.45$) between steers fed 300 and 400 mg of RAC for 14 d. At 28 d, carcass-adjusted ADG was not different ($P = 0.24$) between steers fed RAC at 0 or 300 mg. Similarly, feeding 300 or 400 mg of RAC for 28 d had no effect ($P = 0.48$) on carcass-adjusted ADG. Feeding 400 mg RAC tended ($P = 0.07$; 1.76 vs. 1.71 kg) to increase carcass-adjusted ADG compared to steers fed 0 mg RAC for 28 d. Carcass-adjusted ADG was greater ($P < 0.01$) for steers fed 300 (1.77 kg) and 400 mg (1.84 kg) of RAC for 42 d compared to 0 mg (1.69 kg) RAC fed steers for 42 d. There was a tendency ($P = 0.09$) for an improvement in carcass-adjusted G:F when steers were fed RAC at 400 mg compared to 0 mg for 14 d. Carcass-adjusted G:F was not different ($P = 0.32$) between steers fed 0 and 300 mg of RAC for 14 d or between steers fed 300 and 400 mg of RAC ($P = 0.47$) for 14 d. Carcass-adjusted G:F was 5.3 and 7.1% greater ($P < 0.01$) for steers fed 300 and 400 mg of RAC for 28 d compared to those steers fed 0 mg of RAC for 28 d. Carcass-adjusted G:F was not different ($P = 0.47$) between steers fed 300 and 400 mg of RAC for 28 d. There was a tendency ($P = 0.10$) for 2.8% improvement in carcass-adjusted G:F when steers were fed 300 mg of RAC for 42 d compared with steers fed 0 mg of RAC for 42 d. Feeding 400 mg of RAC for 42 d resulted in a 4.2% improvement ($P = 0.04$) in carcass-adjusted G:F

compared to 0 mg fed steers for 42 d. Carcass-adjusted G:F was not different ($P = 0.65$) between steers fed 300 and 400 mg of RAC for 42 d.

There were no significant ($P \geq 0.25$; Table 5) RAC dose \times duration interaction for carcass characteristics; however, the simple effects will be presented. Hot carcass weight was not different ($P = 0.34$) between steers fed RAC at 0 (382.7 kg) and 300 (384.7 kg) mg for 14 d; however, HCW tended ($P = 0.08$) to be 3.8 kg heavier for steers fed 400 mg of RAC for 14 d compared with steers fed 0 mg of RAC for 14 d. Hot carcass weight was 5.1 and 8.9 kg greater ($P < 0.03$) for steers fed 300 and 400 mg of RAC for 28 d compared with 0 mg (399.9 kg) fed steers for 28 d. Hot carcass weight for steers fed RAC for 42 d at 300 and 400 mg were 7.6 and 9.4 kg heavier ($P < 0.01$) than 0 mg (415.4 kg) fed steers. Using regression analysis to calculate point-in-time estimates, HCW change for steers fed 300 and 400 mg of RAC over 0 mg fed steers is presented in Figure 2. Carcass weight for steers fed both 300 and 400 mg of RAC increased linearly ($P < 0.01$) as RAC duration increased. No other treatment differences ($P > 0.05$) were observed for LM area, dressing percent, marbling score, fat thickness, or calculated yield grade.

There was a tendency ($P = 0.06$; Table 6) for a greater percentage of yield grade 2 carcasses for steers fed 400 mg of RAC compared with 300 mg fed steers for 14 d. Due to this shift, the percentage of yield grade 3 carcasses tended ($P < 0.08$) to be greater for steers fed RAC for 14 d at 0 and 300 mg compared to 400 mg. Feeding 300 mg of RAC for 42 d resulted in a greater ($P = 0.03$) percentage of yield grade 3 carcasses compared to steers fed 400 mg for 42 d. Similarly, the percentage of yield grade 3 carcasses tended (P

= 0.06) to be greater for steers fed 300 mg of RAC for 42 d compared to 0 mg RAC fed steers for 42 d. The percentage of yield grade 4 carcasses tended ($P = 0.08$) to be less for steers fed 300 mg of RAC for 42 d compared with steers fed 400 mg of RAC for 42 d. Steers fed RAC for 42 d at the rate of 0 and 400 mg resulted in no differences ($P = 0.90$) in the percentages of yield grade 4 carcasses. The percent of carcasses grading Choice were not different ($P > 0.65$) for steers fed 0, 300, and 400 mg of RAC for 14 d. At 28 d, the proportion of steers grading Choice and Select were not different ($P \geq 0.22$) between steers fed 0 and 300 mg of RAC. Feeding RAC for 42 d at 400 mg tended ($P = 0.06$) to reduce the percentage of steers grading Choice compared with steers fed 0 mg of RAC. Steers fed 400 mg of RAC increased ($P = 0.02$) the percentage of carcasses grading Select from 6.8 to 23.8% compared to cattle fed 0 mg for 42 d.

DISCUSSION

The primary goal of these two studies were to evaluate the effects of RAC dose and duration on steer growth performance and carcass characteristics when RAC is initiated on the same day but steers are fed for a greater number of days due to the feeding duration of RAC. Figure 1 compares live BW performance profile response curves for steers fed differing RAC doses (200, 300, and 400 mg RAC/steer daily). Steers fed 200 mg of RAC would provide 7.5, 8.3, and 8.5 kg of added live BW over 0 mg fed steers for a 28, 35, and 42 d feeding duration, respectively. These data suggest that feeding steers 200 mg of RAC beyond 35 d is not beneficial because the response curve becomes relatively flat thereafter. Feeding 300 mg of RAC would provide 10.6, 12.0, and 13.0 kg of added live BW, while feeding 400 mg would provide 10.3, 10.9, and 10.7 kg of added live BW over 0 mg fed steers for a 28, 35, and 42 d feeding duration,

respectively. The slope of the line for steers fed 300 mg of RAC appears to be slightly increasing past 35 d, whereas the slope of the line decreases at this point for steers fed 400 mg of RAC. This would suggest the benefit of added live BW is greater when steers are fed 300 mg of RAC than that of steers fed 400 mg of RAC when RAC duration is greater than 35 d.

In Exp. 1, feeding 200 mg of RAC increased live final BW 9.0 kg compared with steers not fed RAC, which is consistent with previous data (Abney et al., 2007), however this response is greater than that reported by Bittner et al. (2016). In addition, these results are greater than those reported by Pyatt et al. (2013), who summarized 32 steer trials evaluating the effects of ractopamine dose and they reported a 6.8 kg increase in live final BW when steers were fed 200 mg of ractopamine compared with steers not fed ractopamine. Others have observed greater response (Boler et al. 2012) of 14.8 kg increased live final BW when steers were fed 200 mg of ractopamine for 28 d. In contrast, Bryant et al. (2010) reported no difference in live final BW when steers were fed 200 mg of ractopamine for 28 d compared with steers not fed ractopamine. In order to make the comparison between feeding 200 mg of RAC for 28 or 42 d in the current study, the simple effects were evaluated. Live final BW was 9.0 kg heavier for steers fed 200 mg of RAC for 28 d than steers fed 0 mg of RAC for 28 d. Likewise, steers fed 200 mg of RAC for 42 d resulted in live final BW being 9.0 kg heavier than steers fed 0 mg of RAC for 42 d. This would suggest that feeding 200 mg of RAC to steers for an additional 14 d does not appear to be beneficial if cattle are marketed on a live final BW basis. In Exp. 2, feeding 300 mg of RAC to steers for 28 or 42 d increased live final BW by 5.7 and 13.4 kg compared with steers fed 0 mg of RAC. Results from this study are

consistent with the summary of Pyatt et al. (2013) where they observed a 10.2 kg increase in live final BW when steers were fed 300 mg of ractopamine, which is in agreement with Avendaño-Reyes et al. (2006). Furthermore, Boler et al. (2012) reported a 14.6 kg increase in live final BW when steers were fed 300 mg of ractopamine. Similar to our findings for steers fed 300 mg of ractopamine for 28 d, Vogel et al. (2009) reported a 6.8 kg increase in live final BW when calf-fed Holstein steers were fed 300 mg of ractopamine. Feeding 400 mg of RAC the last 28 or 42 d improved live final BW by 11.9 and 11.1 kg compared to steers not fed RAC in Exp. 2. Strydom et al. (2009) reported a similar increase of 14.1 kg for change in live final BW when steers were fed 400 mg of ractopamine compared with steers not fed ractopamine. Variable responses in live final BW have been observed in the literature which relates to duration and dosage of ractopamine. Live cattle weights are highly variable and are influenced by many factors such as gut fill (Watson et al., 2013). Furthermore, the time of weighing, feed intake, and environmental factors all impact live BW across and within studies. All these factors increase the variation in live final BW and may partially explain the differences observed in live final BW across experiments when evaluating ractopamine.

Daily DMI was not different between steers fed 0 and 200 mg of RAC in Exp. 2, which is consistent with other reports that have shown no differences in DMI when steers are fed 200 mg of ractopamine (Abney et al., 2007; Bryant et al., 2010; Boler et al., 2012; Pyatt et al., 2013). However, observations from Exp. 2 would suggest a 3.3% decrease in DMI when steers were fed 300 mg of RAC for 28 d compared with steers fed 0 mg of RAC for 28 d. Although significant, the DMI difference was small. The response we observed with feeding 300 mg of ractopamine is greater than reports by Arp et al. (2014)

and Avendaño-Reyes et al. (2006), who found that DMI was decreased by 1.6 and 1.7% for steers fed 300 mg of ractopamine compared with steers not fed ractopamine, respectively. In contrast, others have observed no effect on DMI when feeding 300 mg of ractopamine (Boler et al., 2012; Pyatt et al., 2013). In Exp. 2, feeding 400 mg of RAC did not impact DMI compared to steers fed 0 mg of RAC, which agrees with previous research (Strydom et al., 2009; Arp et al., 2014). These results show that the effects of feeding ractopamine on DMI are inconsistent across experiments. Carcass-adjusted ADG was 10.7% greater when steers were fed 200 mg of RAC compared with 0 mg of RAC in Exp. 1. Greater improvements of 28.4% in ADG have been reported by others when steers were fed 200 mg of ractopamine (Abney et al., 2007). Feeding 300 and 400 mg of RAC for 28 d had no effect on carcass-adjusted ADG compared with steers not fed RAC for 28 d in Exp. 2. Compared to steers fed 0 mg of RAC, carcass-adjusted ADG was improved by 4.7 and 6.5% when steers were fed 300 or 400 mg of RAC for 42 d. These findings are in disagreement with Arp et al. (2014) and Avendaño-Reyes et al. (2006) who observed a 22.2 and 31.6% improvement in ADG when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine. Likewise, Arp et al. (2014) reported a 24.6% improvement in ADG when steers were fed 400 mg of ractopamine compared with steers not fed ractopamine. In Exp. 2, carcass-adjusted G:F was improved by 14.2 % by feeding 200 mg of RAC compared with 0 mg of RAC, and this response is similar to Bittner et al. (2016). Feeding 200 mg of RAC for 28 and 42 d resulted in 11.6 and 8.4% improvements in G:F when compared to steers fed 0 mg of RAC (Table 4). However, greater improvements in G:F (25.8%) have been reported when steers were fed 200 mg of ractopamine (Abney et al., 2007). Feeding 300 mg of

RAC for 28 d improved G:F 5.7% whereas feeding 400 mg of RAC improved G:F by 7.1% compared with steers fed 0 mg of RAC in Exp. 2. Conversely, Arp et al. (2014) noted a 23.1% improvement in G:F when steers were fed either 300 or 400 mg of ractopamine compared with steers not fed ractopamine. In the Freedom of Information Summary (FDA, 2009), feed efficiency was improved by 16.0% when steers were fed 400 mg of ractopamine for 42 d compared with steers not fed ractopamine. In Exp. 2, improvements in carcass-adjusted ADG and feed efficiency when feeding ractopamine were lesser than what previous data would suggest. One explanation for variable responses in percentage change in ADG and G:F across studies relates to duration of the period to establish ADG. In Exp. 2, ADG response is based on the overall feeding period. Many others have reported a % change for just the duration of feeding ractopamine. Clearly, percentage response should be evaluated carefully and across similar durations for different experiment comparisons. More critically than ADG response is probably weight responses (live BW, carcass-adjusted BW, and HCW) as these responses are independent of a duration in calculation of the variable. If G:F response is evaluated, duration used to calculate ADG and thus influence on G:F should be either across the entire feeding period or only during the time ractopamine is fed, but not inconsistently across studies. This is difficult to compare across studies if BW data are not collected or presented for just the ractopamine duration or for the entire feeding period.

Figure 2 compares HCW change for steers fed 300 and 400 mg RAC over 0 mg fed steers. The linear equation ($R^2 = 0.99$; $y = 0.1777x$) would predict that feeding 300 mg of RAC would provide 5.0, 6.2, and 7.5 kg of added HCW, while feeding 400 mg of RAC ($R^2 = 0.74$; $y = 0.2536x$) would provide 7.1, 8.9, and 10.7 kg of added HCW over

0 mg fed steers for a 28, 35, and 42 d feeding duration, respectively, which is the legally approved duration for feeding ractopamine hydrochloride to beef cattle. Statistically, the slope of the line for feeding 400 mg of RAC is linear; however, the actual data points that make up this line appear quadratic. A plateau for HCW response across time, especially at large dosages, may be logical and explained by desensitization of β -AA receptors from prolonged exposure to β -AA (Johnson, 2004). However, the quadratic response was not significant ($P = 0.32$) and so we conclude these are linear responses up to 42 d durations.

In Exp. 1, HCW was 4.7 kg greater for steers fed 200 mg of RAC compared with 0 mg of RAC fed steers. Steers fed 200 mg of RAC the last 28 or 42 d increased HCW by 5.5 and 3.9 kg compared with steers fed 0 mg of RAC. This response is similar to the results of Abney et al. (2007) and Pyatt et al. (2013), where they reported 6.1 and 6.9 kg increases in HCW when steers were fed 200 mg of ractopamine. In Exp. 2, feeding 300 mg of RAC the last 28 or 42 d increased HCW by 5.1 and 7.6 kg compared with steers fed 0 mg of RAC. These findings agree with Bohrer et al. (2014) who reported an increase in HCW of 6.6 kg when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine. Furthermore, Pyatt et al. (2013) reported HCW being 9.2 kg heavier for steers fed 300 mg of ractopamine compared with steers not fed ractopamine, and Avendaño-Reyes et al. (2006) observed a 13.6 kg increase in HCW. Boler et al. (2012) fed 300 mg of ractopamine for 28 d and they observed a 14.9 kg increase in HCW compared with steers not fed ractopamine. Feeding 400 mg of RAC the last 28 or 42 d increased HCW by 8.9 and 9.4 kg compared to steers fed 0 mg of RAC in Exp. 2. In contrast, Arp et al. (2014) noted a 6.3 kg increase in HCW when steers were fed 400 mg of ractopamine for 30 d compared with steers not fed ractopamine. Furthermore,

Strydom et al. (2009) observed a 7.0 kg increase in HCW when steers were fed 400 mg of ractopamine compared with steers not fed ractopamine.

In our study, feeding 200 mg of RAC had no effect on dressing percent, marbling score, fat thickness, LM area, and calculated yield grade when compared with steers fed 0 mg of RAC. Likewise, Arp et al. (2014) reported no differences in these carcass traits when steers were fed 200 mg of ractopamine. In contrast, other studies have shown increases in dressing percent and LM area when steers were fed 200 mg of ractopamine compared with steers not fed ractopamine (Bryant et al., 2010; Boler et al., 2012; Bittner et al., 2016). Dressing percent was not different between steers fed 0 and 300 mg of RAC. Previous studies have reported no differences in dressing percent when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine (Arp et al., 2014; Bohrer et al., 2014). However, Boler et al. (2012) reported an increase of 1.12% in dressing percent when steers were fed 300 mg of ractopamine. Feeding 300 mg of RAC had no effect on marbling score compared with steers fed 0 mg of RAC. Bohrer et al. (2014) reported no differences in marbling score when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine, which agrees with the current study. In contrast, Arp et al. (2014) noted a decrease in marbling score when steers were fed 300 mg of ractopamine. In the present study, fat thickness was not different between steers fed 0 and 300 mg of RAC, which agrees with previous studies (Boler et al., 2012; Pyatt et al., 2013; Arp et al., 2014; Bohrer et al., 2014). Longissimus muscle area was not different between steers fed 0 and 300 mg of RAC. Previous studies have shown inconsistent results on LM area when steers were fed 300 mg of ractopamine and compared with steers not fed ractopamine. Arp et al. (2014) reported no differences in

LM area when steers were fed 300 mg of ractopamine, whereas Boler et al. (2012) have shown increases of 4.0 cm² in LM area. In the current study, feeding 400 mg of RAC had no effect on dressing percent, marbling score, and fat thickness when compared with steers fed 0 mg of RAC. These findings agree with previous research when steers were fed 400 mg of ractopamine (Strydom et al., 2009; Arp et al., 2014). However, due to the fact that the steers fed RAC for 42 d were fed 14 d past their target marketing date, which resulted in an increase in fat thickness, feeding steers longer could partially explain the fact that feeding a higher dose of RAC had no effect on marbling score. Longissimus muscle area was not different between steers fed 0 and 400 mg of RAC for 28 d in the current study, which agrees with Strydom et al. (2009). Conversely, Arp et al. (2014) reported an increase of 2.4 cm² in LM area when steers were fed 400 mg of ractopamine compared with steers not fed ractopamine.

Calculated yield grade was not different between steers fed 0 and 200 mg of RAC in the current study. This coincides with previous data suggesting that feeding 200 mg of ractopamine has no effect (Abney et al., 2007; Griffin et al., 2009; Bryant et al., 2010; Scramlin et al., 2010; Boler et al., 2012; Arp et al., 2014) on calculated yield grade when compared with steers not fed ractopamine. Conversely, Bittner et al. (2016) reported a linear decrease in calculated yield grade when steers were fed 200 mg of ractopamine compared with steers not fed ractopamine. When comparing steers fed 300 and 400 mg of RAC to steers fed 0 mg of RAC in the present study, calculated yield grade was not different among treatments. Previous studies have reported conflicting results for calculated yield grade when steers were fed ractopamine. Arp et al. (2014) and Boler et al. (2012) reported no differences in calculated yield grade between steers fed 300 mg of

ractopamine and steers not fed ractopamine. However, the summary of Pyatt et al. (2013) noted a linear decrease in calculated yield grade. In contrast, Bohrer et al. (2014) reported a tendency for an increase in yield grade when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine. Arp et al. (2014) reported no difference in yield grade between steers fed 400 mg of ractopamine and steers not fed ractopamine, which agrees with the present study. Bohrer et al. (2014) reported no differences in the proportion of cattle grading Prime, Choice, and Select when steers were fed 300 mg of ractopamine compared with steers not fed ractopamine, which agrees with the current study. The distribution of steers grading Prime, Choice, and Select were not different between steers fed 0 and 400 mg of RAC for 28 d in the current study. These findings agree with Arp et al. (2014), who reported no differences in the proportion of cattle grading Prime, Choice, and Select when steers were fed 400 mg of ractopamine for 30 d and compared with steers not fed ractopamine. However, the percentage of steers grading Prime and Choice decreased and the percentage of steers grading Select increased when steers were fed 400 mg of RAC compared with steers fed 0 mg of RAC for 42 d.

Overall, the results from these studies confirm that feeding steers RAC improves live final BW, feed efficiency, and HCW when fed for the last 28 or 42 d of the finishing period. Furthermore, our data would suggest that the optimum duration for feeding steers 200 mg of RAC would be 28 d. In Exp. 2, steers were fed RAC for 14 d in order to develop the response curves for both live BW and HCW change. A feeding duration of 14 d is not approved for RAC; therefore, conclusions are based on 28 and 42 d of feeding RAC. Feeding RAC at 200, 300, or 400 mg/d dosages resulted in quadratic increases in

live final BW suggesting duration is likely optimized at 28 days as less return is observed from d 28 to d 42. However, linear increases in HCW were observed across durations for the different dosages suggesting duration can be longer if marketing on a HCW basis.

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Table 4.1. Dry matter composition of finishing diets for Exp. 1 and 2

Ingredient, %	Exp. 1 ¹	Exp. 2 ²
High-moisture corn	58.5	28.0
Dry-rolled corn		18.0
Sweet Bran ³	30.0	20.0
Modified distillers grains plus solubles		25.0
Wheat Straw		5.0
Alfalfa Hay	7.5	
Dry Supplement ⁴		
Fine ground corn	2.1440	1.5118
Limestone	1.3320	1.9980
Salt	0.3000	0.3000
Tallow	0.1100	0.1000
Beef trace mineral ⁵	0.0500	0.0500
Vitamin A-D-E ⁶	0.0200	0.0150
Rumensin ⁷	0.0167	0.0165
Tylan ⁸	0.0094	0.0087
Nutrient Composition, %		
DM	69.4	70.2
NDF	20.1	23.1
CP	14.6	16.4
Ca	0.65	0.81
P	0.45	0.58

¹ Ractopamine hydrochloride (Elanco Animal Health, Greenfield, IN) was provided daily in a meal supplement at 4% of the diet DM at a rate of 0 or 200 mg RAC/steer daily during the treatment phase.

² Ractopamine hydrochloride (Elanco Animal Health) was delivered daily during the treatment phase via top-dress at either 0, 300, or 400 mg RAC/steer daily.

³ Sweet Bran, Cargill Corn Milling, Blair, NE.

⁴ Supplement formulated to be fed at 4% of diet DM.

⁵ Premix contained 6% Zn, 5% Fe, 4% Mn, 2% Cu, 0.28% Mg, 0.2% I, and 0.05% Co.

⁶ Premix contained 29,974 IU/g vitamin A, 5,995 IU/g vitamin D, 7.5 IU/g vitamin E.

⁷ Premix contained 176 g of monensin/kg (Rumensin; Elanco Animal Health, Greenfield, IN) for Exp. 1 or 199 g of monensin/kg for Exp. 2.

⁸ Premix contained 88 g of tylosin/kg (Tylan; Elanco Animal Health, Greenfield, IN) for Exp. 1 and 2.

Table 4.2. Growth performance of steers fed 0 and 200 mg ractopamine hydrochloride (RAC)/steer daily for 28 or 42 d at the end of the finishing period (Exp. 1)

Dose:	0		200		<i>P</i> -value			
Duration:	28 d	42 d	28 d	42 d	SEM ²	Int. ³	Dose ⁴	Duration ⁵
Live Performance								
Initial BW, kg	539	539	539	539	-	-	-	-
Live Final BW ⁶ , kg	585 ^d	608 ^b	594 ^c	617 ^a	2	0.98	<0.01	<0.01
DMI, kg/d	10.5 ^b	11.0 ^a	10.6 ^{ab}	10.9 ^a	0.2	0.80	0.89	<0.01
ADG ⁷ , kg	1.68 ^b	1.64 ^b	1.94 ^a	1.85 ^a	0.04	0.51	<0.01	0.10
G:F	0.160 ^c	0.150 ^d	0.184 ^a	0.169 ^b	0.003	0.44	<0.01	<0.01
Carcass-Adjusted Performance								
Final BW ⁸ , kg	594 ^d	620 ^b	603 ^c	628 ^a	2	0.69	<0.01	<0.01
ADG ⁹ , kg	1.99 ^{bc}	1.93 ^c	2.25 ^a	2.10 ^{ab}	0.06	0.41	<0.01	0.08
G:F	0.189 ^{bc}	0.176 ^c	0.213 ^a	0.192 ^b	0.005	0.40	<0.01	<0.01

^{abcd}Means with different superscripts differ ($P < 0.05$)

¹0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN);
200 = 200 mg/steer daily of ractopamine. Diets were fed for the last 28 or 42 d of the finishing period.

²Standard error of the treatment means.

³Int. = P -value for the RAC dose \times duration interaction.

⁴Dose = P -value for the main effect of RAC dose.

⁵Duration = P -value for the main effect of RAC duration.

⁶Live final BW shrunk 4%.

⁷Calculated using live final BW.

⁸Calculated from carcass weight, adjusted to 63% common dressing percent.

⁹Calculated using carcass-adjusted final BW.

Table 4.3. Carcass characteristics of steers fed 0 and 200 mg ractopamine hydrochloride (RAC)/steer daily for 28 or 42 d at the end of the finishing period (Exp. 1)

Dose:	0		200		<i>P</i> -value			
Duration:	28 d	42 d	28 d	42 d	SEM ²	Int. ³	Dose ⁴	Duration ⁵
HCW, kg	374 ^d	391 ^b	380 ^c	395 ^a	1	0.71	<0.01	<0.01
Dressing percent	63.9 ^b	64.3 ^a	63.9 ^{ab}	64.1 ^{ab}	0.2	0.45	0.50	0.04
Marbling score ⁶	516 ^a	517 ^a	510 ^a	522 ^a	8	0.46	0.96	0.42
Fat thickness, cm	1.43 ^b	1.64 ^a	1.39 ^b	1.57 ^{ab}	0.07	0.85	0.44	<0.01
LM area, cm ²	87.6 ^b	93.9 ^a	89.2 ^b	94.1 ^a	1.0	0.48	0.35	<0.01
Calculated YG ⁷	3.2 ^a	3.2 ^a	3.1 ^a	3.2 ^a	0.1	0.69	0.57	0.48
Yield grade, %								
1	3.76 ^a	6.44 ^a	10.54 ^a	6.63 ^a	3.97	0.28	0.25	0.95
2	30.74 ^a	30.00 ^a	33.55 ^a	28.53 ^a	5.76	0.68	0.91	0.58
3	47.11 ^a	45.19 ^a	47.11 ^a	42.02 ^a	6.04	0.77	0.77	0.53
4 and 5	15.98 ^{ab}	16.10 ^{ab}	7.09 ^b	20.51 ^a	5.17	0.11	0.36	0.07
Quality grade, %								
Choice and greater	60.39 ^a	54.74 ^a	53.18 ^a	62.69 ^a	6.09	0.18	0.94	0.73
Select	39.11 ^a	43.52 ^a	46.33 ^a	36.80 ^a	6.11	0.22	0.97	0.65

^{abcd}Means with different superscripts differ ($P < 0.05$)

¹0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 200 = 200 mg/steer daily of ractopamine. Diets were fed for the last 28 or 42 d of the finishing period.

²Standard error of the treatment means.

³Int. = P -value for the RAC dose \times duration interaction.

⁴Dose = P -value for the main effect of RAC dose.

⁵Duration = P -value for the main effect of RAC duration.

⁶Marbling Score: 400 = slight, 500 = small, 600 = modest, etc.

⁷Calculated yield grade (YG) = $2.50 + (6.35 \times \text{fat thickness, cm}) + (0.2 \times \text{KPH, \%}) + (0.0017 \times \text{HCW, kg}) - (2.06 \times \text{LM area, cm}^2)$.

Table 4.4. Growth performance of steers fed 0, 300, and 400 mg ractopamine hydrochloride (RAC)/steer daily for 14, 28, or 42 d at the end of the finishing period (Exp. 2)

Duration: Dose ¹ :	14 d			28 d			42 d			SEM ²	Int. ³	Dose ⁴	Dur. ⁵
	0	300	400	0	300	400	0	300	400				
Live Performance													
Initial BW ⁶ , kg	404	404	403	402	404	404	404	405	403	1	0.15	0.59	0.60
Initial BW ⁷ , kg	594	595	591	597	592	585	593	592	593	-	-	-	-
Live final BW ⁸ , kg	628.2 ^e	630.6 ^e	630.9 ^e	641.8 ^d	647.6 ^{cd}	653.7 ^c	668.1 ^b	681.5 ^a	679.2 ^a	3	0.03	0.01	<0.01
Over Control, kg	-	2.4	2.7	-	5.8	11.9	-	13.4	11.1				
DMI, kg/d	12.0 ^{ab}	12.0 ^{ab}	12.0 ^{ab}	12.2 ^a	11.8 ^b	11.8 ^b	12.0 ^{ab}	12.2 ^{ab}	12.3 ^{ab}	0.2	0.08	0.67	0.56
ADG ⁹ , kg	1.83	1.86	1.86	1.76	1.79	1.83	1.76	1.84	1.84	0.06	0.14	0.02	0.08
G:F	0.153 ^a	0.155 ^a	0.156 ^a	0.144 ^c	0.152 ^{ab}	0.156 ^a	0.146 ^{bc}	0.152 ^a	0.150 ^{abc}	0.001	0.03	<0.01	0.23
Carcass-Adjusted Performance													
Final BW ¹⁰ , kg	608	611	613	636	643	646	659	671	674	3	0.30	<0.01	<0.01
ADG, kg	1.66	1.69	1.71	1.71	1.75	1.76	1.69	1.77	1.80	0.05	0.46	0.01	<0.01
G:F	0.138	0.141	0.143	0.140	0.148	0.150	0.142	0.146	0.148	0.001	0.69	0.01	0.04

^{abcde}Means with different superscripts differ ($P < 0.05$)

¹0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine; 400 = 400 mg/steer daily of ractopamine.

²Standard error of the treatment means.

³Int. = P -value for the RAC dose \times duration interaction.

⁴Dose = P -value for the main effect of RAC dose.

⁵Dur. = P -value for the main effect of RAC duration.

⁶Initial BW = BW collected at the beginning of the experiment.

⁷Initial BW = BW collected on d of RAC initiation. Used as a covariate in the analysis.

⁸Live final BW measured by weighing cattle on pen scale day of shipping and applying a 4% pencil shrink.

⁹Calculated using live final BW.

¹⁰Calculated from HCW divided by a common dressing percent (63%).

Table 4.5. Carcass characteristics of steers fed 0, 300, and 400 mg ractopamine hydrochloride (RAC)/steer daily for 14, 28, or 42 d at the end of the period (Exp. 2)

Duration:	14 d			28 d			42 d			SEM ²	Int. ³	Dose ⁴
Dose ¹ :	0	300	400	0	300	400	0	300	400			
HCW, kg	382.7	384.7	386.5	399.9	405.0	408.8	415.4	422.9	424.7	2.3	0.30	<0.01
Over Control, kg	-	2.0	3.8	-	5.1	8.9	-	7.6	9.4			
Dressing ⁶ , %	60.9	61.0	61.2	62.4	62.6	62.3	62.2	62.2	62.7	0.4	0.67	0.64
Marbling ⁷	440	430	434	465	453	470	485	486	476	11	0.82	0.76
LM area, cm ²	86.2	84.8	84.6	87.0	89.0	88.4	89.0	89.6	90.5	0.2	0.25	0.79
Fat thickness, cm	1.23	1.29	1.29	1.48	1.41	1.46	1.49	1.50	1.50	0.02	0.72	0.92
Calculated YG ⁸	3.15	3.27	3.29	3.52	3.36	3.48	3.55	3.56	3.55	0.10	0.52	0.78

^{abcde}Means with different superscripts differ ($P < 0.05$)

¹0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine; 400 = 400 mg/steer daily of ractopamine.

²Standard error of the treatment means.

³Int. = P -value for the RAC dose \times duration interaction.

⁴Dose = P -value for the main effect of RAC dose.

⁵Dur. = P -value for the main effect of RAC duration.

⁶DP = Dressing Percent; calculated from HCW divided by live final BW, with a 4% pencil shrink applied.

⁷Marbling Score: 300 = Slight, 400 = Small, 500 = Modest, etc.

⁸Calculated yield grade = $2.50 + (6.35 \times \text{fat thickness, cm}) + (0.2 \times \text{KPH, \%}) + (0.0017 \times \text{HCW, kg}) - (2.06 \times \text{LM area, cm}^2)$.

Table 4.6. Yield and quality grade distribution of steers fed 0, 300, or 400 mg/steer daily of RAC for 14, 28, or 42 days at the end of the finishing period (Exp. 2)

Duration:	14 d			28 d			42 d			SEM ²	Int. ³	Dose ⁴	Dur. ⁵
Dose ¹ :	0	300	400	0	300	400	0	300	400				
Yield grade,%													
1 and 2	22.58	17.19	30.00	29.51	38.10	38.60	22.41	14.75	20.97	6.44	0.51	0.29	<0.01
2	19.35	15.63	30.00	24.59	33.33	35.09	22.41	13.11	17.74	6.32	0.31	0.25	0.01
3	74.19	75.00	58.33	54.10	55.56	54.39	44.83	62.30	41.94	6.60	0.35	0.05	<0.01
4	3.23	7.81	11.67	16.39	6.35	7.02	32.76	19.67	33.87	6.16	0.21	0.47	<0.01
4 and 5	3.23	7.81	11.67	16.39	6.35	7.02	32.76	22.95	37.10	6.16	0.21	0.50	<0.01
Quality grade,%													
Prime & Choice	67.74	67.19	65.57	80.65	73.02	82.46	91.53	85.25	76.19	6.08	0.26	0.30	<0.01
Choice	67.74	64.06	65.57	77.42	73.02	82.46	89.83	81.97	76.19	6.08	0.39	0.39	<0.01
Select	30.65	32.81	34.43	17.74	26.98	17.54	6.78	14.75	23.81	6.08	0.22	0.14	<0.01
Select & Standard	32.26	32.81	34.43	19.35	26.98	17.54	8.48	14.75	23.81	6.08	0.26	0.50	<0.01

^{abcd}Means with different superscripts differ ($P < 0.05$)

¹0 = 0 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine; 400 = 400 mg/steer daily of ractopamine.

²Standard error of the treatment means.

³Int. = P -value for the RAC dose \times duration interaction.

⁴Dose = P -value for the main effect of RAC dose.

⁵Dur. = P -value for the main effect of RAC duration.

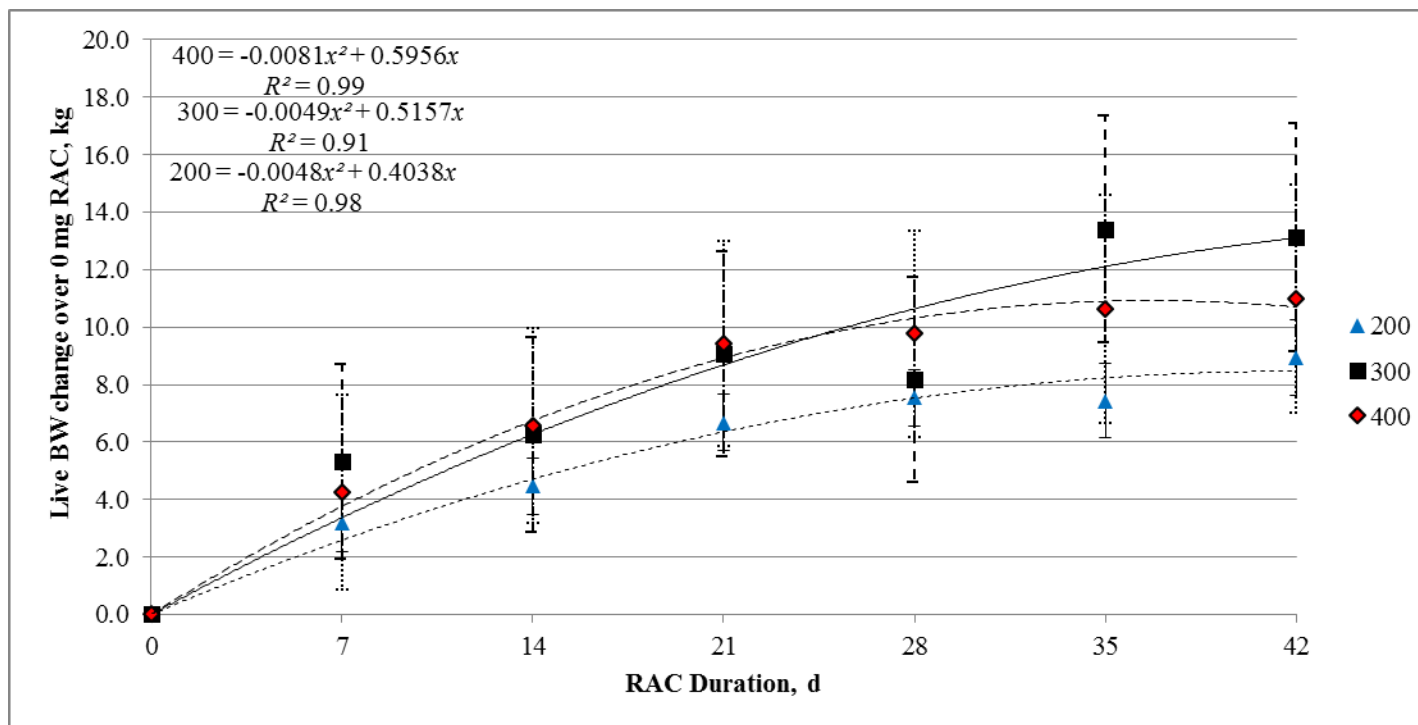


Figure 4.1. Live BW change when feeding 200, 300, and 400 mg RAC over 0 mg of RAC^{abc} (Exp. 1 & Exp. 2)

^a200 = 200 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 300 = 300 mg/steer daily of ractopamine; 400 = 400 mg/steer daily of ractopamine.

^bGrowth performance is calculated on a shrunk basis (4%).

^cDays 7-28 has 28 RAC 200 mg pens averaged together, days 35-42 has 14 RAC 200 mg pens averaged together; Days 7-14 has 24 RAC 300 mg pens averaged together and 24 RAC 400 mg pens averaged together, days 21-28 has 16 pens for 300 mg and 16 pens for 400 mg, days 35-42 has 8 pens for 300 mg and 8 pens for 400 mg. Quad. = Quadratic.

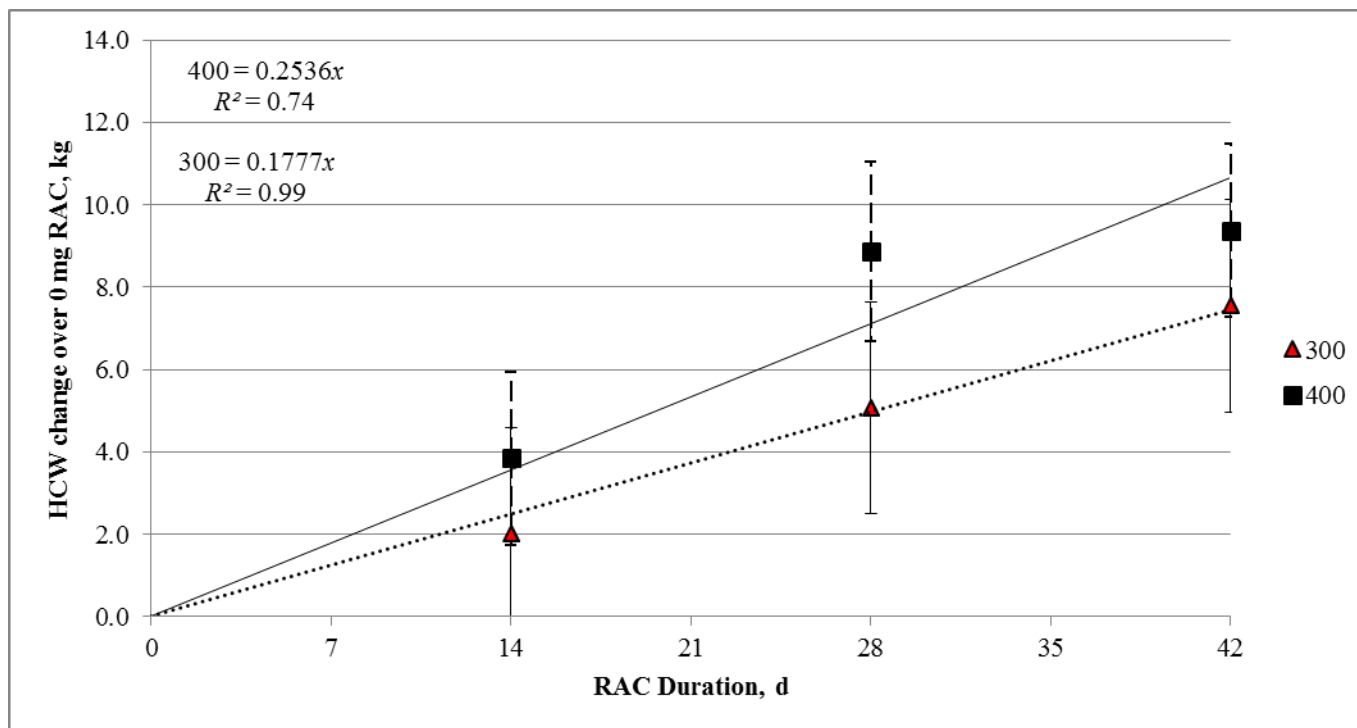


Figure 4.2. Hot carcass weight change when feeding 300 and 400 mg RAC over 0 mg of RAC^{ab} (Exp. 2).

^a300 = 300 mg/steer daily of ractopamine hydrochloride (Optaflexx, Elanco Animal Health, Greenfield, IN); 400 = 400 mg/steer daily of ractopamine.

^bDays 7-14 has 24 RAC 300 mg pens averaged together and 24 RAC 400 mg pens averaged together, days 21-28 has 16 pens for 300 mg and 16 pens for 400 mg, and days 35-42 has 8 pens for 300 mg and 8 pens for 400 mg. Lin. = Linear.